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(71) 出願人 000005821

松下電器産業株式会社

大阪府門真市大字門真1006番地

(72) 発明者 榊間 博

大阪府門真市大字門真1006番地 松下電器
産業株式会社内

(72) 発明者 杉田 康成

大阪府門真市大字門真1006番地 松下電器
産業株式会社内

(74) 代理人 100078282

弁理士 山本 秀策

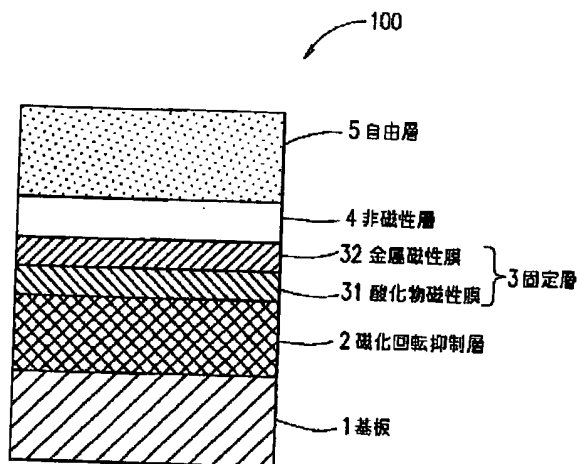
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(54) 【発明の名称】 磁気抵抗効果素子とその製造方法、磁気抵抗効果型ヘッド、磁気記録装置、磁気抵抗効果メモリ素子

(57) 【要約】

【課題】 熱的安定性と高MR比とを有する磁気抵抗効果素子を提供する。

【解決手段】 磁気抵抗効果素子は、外部磁界により容易に磁化回転する自由層と、第1非磁性層と、該第1非磁性層に対して該自由層の反対側に設けられ、該外部磁界により容易には磁化回転しない第1固定層とを含み、該第1固定層と該自由層との少なくとも一方は、該第1非磁性層と接する第1金属磁性膜と、第1酸化物磁性膜とを含む。



【特許請求の範囲】

【請求項1】 外部磁界により容易に磁化回転する自由層と、
第1非磁性層と、
該第1非磁性層に対して該自由層の反対側に設けられ、
該外部磁界により容易には磁化回転しない第1固定層と
を含み、
該第1固定層と該自由層との少なくとも一方は、該第1
非磁性層と接する第1金属磁性膜と、第1酸化物磁性膜
とを含む磁気抵抗効果素子。

【請求項2】 前記第1固定層は、前記第1金属磁性膜
と、前記第1酸化物磁性膜とを含む、請求項1記載の磁
気抵抗効果素子。

【請求項3】 前記自由層に対して前記第1非磁性層の
反対側に設けられる第2非磁性層と、
該第2非磁性層に対して該自由層の反対側に設けられ、
該外部磁界により容易には磁化回転しない第2固定層と
をさらに含む、請求項1記載の磁気抵抗効果素子。

【請求項4】 前記自由層は、前記第1金属磁性膜と、
前記第1酸化物磁性膜とを含む、請求項1記載の磁気抵
抗効果素子。

【請求項5】 前記自由層に対して前記第1非磁性層の
反対側に設けられ、平坦性の良好な酸化物非磁性膜をさ
らに含む、請求項2記載の磁気抵抗効果素子。

【請求項6】 前記第1酸化物磁性膜と磁氣的に結合す
る磁化回転抑制層をさらに含む、請求項1記載の磁気抵
抗効果素子。

【請求項7】 前記自由層は、前記酸化物磁性膜に対し
て前記第1金属磁性膜の反対側に設けられる第2金属磁
性膜をさらに含む、請求項4記載の磁気抵抗効果素子。

【請求項8】 前記第1固定層と磁氣的に結合するが磁
化回転抑制層をさらに含む、請求項1記載の磁気抵抗効
果素子。

【請求項9】 前記第1固定層は、前記第1酸化物磁性
膜に対して前記第1金属磁性膜の反対側に設けられる第
2金属磁性膜をさらに含む、請求項1記載の磁気抵抗効
果素子。

【請求項10】 前記第1固定層は、前記第1酸化物磁
性膜に対して前記第1金属磁性膜の反対側に設けられる
第2金属磁性膜と、
第3金属磁性膜と、
該第2金属磁性膜と該第3金属磁性膜とを反強磁性的に
交換結合する交換結合用非磁性膜とをさらに含む、請求
項1記載の磁気抵抗効果素子。

【請求項11】 前記第1固定層は、前記第1酸化物磁
性膜に対して前記第1金属磁性膜の反対側に設けられる
非磁性膜と、
該非磁性膜を介して該第1酸化物磁性膜と磁氣的に交換
結合する第2酸化物磁性膜をさらに含む、請求項1記載
の磁気抵抗効果素子。

【請求項12】 前記第1酸化物磁性膜は、Fe元素を
含有する、請求項1記載の磁気抵抗効果素子。

【請求項13】 前記第1酸化物磁性膜は、Fe元素と
X元素とを含有する、請求項1記載の磁気抵抗効果素
子。ただしXはAl, Si, B, Nから成る群より選ば
れる1種もしくは2種以上の元素である。

【請求項14】 前記第1酸化物磁性膜は、 MFe_2O_4
(MはFe, Co, Niから選ばれる1種もしくは2種
以上の元素)を主成分とする、請求項1記載の磁気抵抗
効果素子。

【請求項15】 前記第1酸化物磁性膜は、 Fe_3O_4 を
主成分とする、請求項1記載の磁気抵抗効果素子。

【請求項16】 前記第1酸化物磁性膜は、 $CoFe_2O_4$
を主成分とする請求項1記載の磁気抵抗効果素子。

【請求項17】 前記磁化回転抑制層は、P-Mn系
(PはPt, Ni, Pd, Ir, Rh, Ru, Crから
選ばれる1種もしくは2種以上の元素)合金より成る、
請求項6記載の磁気抵抗効果素子。

【請求項18】 前記磁化回転抑制層は、 $\alpha-Fe_2O_3$ 、 NiO のいずれか、もしくはこれらの積層膜から
成る、請求項6記載の磁気抵抗効果素子。

【請求項19】 前記該磁化回転抑制層は、 $(AB)_2O_x$ 層から成ることを特長とする請求項6記載の磁気抵抗
効果素子。ただし $(AB)_2O_x$ とはAとB元素を足し
たものとO元素との比が2:Xであることを示し、Oは
酸素原子2.8<X<3.2の条件を満足し、かつ原子
A、B、Oのイオン半径をそれぞれ R_a 、 R_b 、 R_o
として次式

$$t = (R_a + R_o) / (\sqrt{2} \cdot (R_b + R_o))$$

で定義されるtが0.8<t<0.97であることを満
足するものである。

【請求項20】 前記 $(AB)_2O_x$ 層のBがFeを主成
分とする遷移金属元素である、請求項19に記載の磁気
抵抗効果素子。

【請求項21】 前記 $(AB)_2O_x$ 層のAが(Y, La
を含む)希土類元素から選ばれる1種もしくは2種以
上の元素である、請求項19に記載の磁気抵抗効果素子。

【請求項22】 前記第1酸化物磁性膜は、前記第1金
属磁性膜の酸化物である、請求項1に記載の磁気抵抗効
果素子。

【請求項23】 前記第1金属磁性膜は、Co-Fe合
金からなる、請求項22に記載の磁気抵抗効果素子。

【請求項24】 特に該自由層は、非磁性膜と、
前記非磁性膜を介して反強磁性的に交換結合した、膜厚
または飽和磁化の異なる2つの金属磁性膜とを含む、請
求項1記載の磁気抵抗効果素子。

【請求項25】 前記磁気抵抗効果素子の膜面の上下に
配置される電極をさらに含む、
電流を前記膜面に垂直に流す、請求項1記載の磁気抵抗
効果素子。

【請求項26】 請求項1記載の磁気抵抗効果素子と、シールド部とを具備する磁気抵抗効果型ヘッド。

【請求項27】 請求項1記載の磁気抵抗効果素子と、検知すべき磁界を前記磁気抵抗効果素子に導入するヨークとを具備する磁気抵抗効果型ヘッド。

【請求項28】 請求項26記載の磁気抵抗効果型ヘッドと、

記録媒体と該磁気抵抗効果型ヘッドとのトラッキングを制御するサーボ部と、

該磁気抵抗効果型ヘッドが該記録媒体に記録再生する信号を処理する信号処理部とを備える磁気記録装置。

【請求項29】 請求項1記載の磁気抵抗効果素子と、該磁気抵抗効果素子から情報を読み出すための情報読出用導体線と、

該情報を記録するための情報記録用導体線とを具備する磁気抵抗効果メモリ素子。

【請求項30】 請求項1記載の磁気抵抗効果素子の製造方法であって、前記第1酸化物磁性膜を、酸化物ターゲットを用いてスパッタ法により形成する第1工程を包含する磁気抵抗効果素子の製造方法。

【請求項31】 前記酸化物ターゲットは Fe_3O_4 を含む、請求項30に記載の磁気抵抗効果素子の製造方法。

【請求項32】 前記第1工程は、不活性ガスと酸素ガスをを用いてスパッタ法により前記第1酸化物磁性膜を形成する第2工程を包含する、請求項30に記載の磁気抵抗効果素子の製造方法。

【請求項33】 前記第1工程は、不活性ガスと酸素ガスをを用いてスパッタ法により前記第1酸化物磁性膜を形成する第2工程を包含する、請求項31に記載の磁気抵抗効果素子の製造方法。

【請求項34】 前記酸化物ターゲットは CoFe_2O_4 を含む、請求項30に記載の磁気抵抗効果素子の製造方法。

【請求項35】 基板上に直接または下地層を介して、外部磁界により容易に磁化回転する自由層、非磁性層、外部磁界により容易には磁化回転しない固定層の金属磁性膜を順次積層する第1の工程と、

該固定層の該金属磁性膜の表面を酸化させる第2の工程と、

該金属磁性膜の表面上に酸化物磁性膜を形成する第3の工程と、

該酸化物磁性膜の上に磁化回転抑制層を更に形成する第4の工程とを包含する磁気抵抗効果素子の製造方法。

【請求項36】 前記第2の工程は、プラズマ酸化法を含む、請求項35記載の磁気抵抗効果素子の製造方法。

【請求項37】 前記第2の工程は、酸素ラジカル源から発生した酸素ラジカルにより、前記金属磁性膜の前記表面を酸化する工程を含む、請求項35記載の磁気抵抗効果素子の製造方法。

【請求項38】 前記第2の工程は、自然酸化法を含

む、請求項35記載の磁気抵抗効果素子の製造方法。

【請求項39】 前記第2の工程は、イオン源より発生した酸素イオンを用いて前記金属磁性膜の前記表面を酸化する工程を含む、請求項35記載の磁気抵抗効果素子の製造方法。

【請求項40】 基板上に直接または下地層を介して、外部磁界により容易に磁化回転する自由層、非磁性層、外部磁界により容易には磁化回転しない固定層の第1金属磁性膜を順次積層する第1の工程と、

該固定層の酸化物磁性膜を反応性スパッタリング法により形成する第2の工程と、

該酸化物磁性膜その上に該固定層の第2金属磁性膜を形成する第3の工程と、

該第2金属磁性膜上に磁化回転抑制層を更に形成する第4の工程とを包含する磁気抵抗効果素子の製造方法。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は外部磁界に対して磁気抵抗変化により大きな出力を生ずる磁気抵抗効果素子と、それを用いて構成される高密度磁気記録再生に適した磁気抵抗効果型ヘッド、及びこれを用いたHDD等の磁気記録装置とその製造方法に関するものである。

【0002】

【従来の技術】近年、HDD（ハードディスクドライブ）の高密度化は著しく、媒体に記録された磁化を読みとる再生磁気ヘッドの進歩も著しい。中でも巨大磁気抵抗効果を利用したスピナバルブと呼ばれる磁気抵抗効果素子（MR素子）は、現在用いられている磁気抵抗効果型ヘッド（MRヘッド）の感度を大幅に上昇されるものとして盛んに研究されている。

【0003】スピナバルブは、非磁性層を介して2つの強磁性体層が配置され、一方の磁性層（固定層）の磁化方向を磁化回転抑制層（ピンニング層）による交換バイアス磁界で固定し（この時の強磁性体層と磁化回転抑制層を合わせて交換結合膜と呼ぶ）、もう一方の磁性層（自由層）の磁化方向を外部磁界に応じて比較的自由に動かすことにより、固定層と自由層の磁化方向の相対角度を変化させて、電気抵抗の変化を生じさせるものである。

【0004】スピナバルブ膜に用いられる材料としては、当初、磁性膜として Ni-Fe 膜、非磁性膜として Cu 、磁化回転抑制層として Fe-Mn を用いたもので磁気抵抗変化率（MR比）が約2%のものが提案された（ジャーナル オブマグネティズム アンド マグネティック マテリアルズ 93 第101項（1991年）（Journal of Magnetism and Magnetic Materials 93, p101, 1991））。このように、磁化回転抑制層として FeMn 膜を用いたものはMR比が小さく、またブロッキング温度（磁化回転抑制層による固定層の

磁化固定効果が無くなる温度)が十分高くなく、またFeMn自体に耐食性に難点があるので、種々の磁化回転抑制層を用いたスピバルブ膜が提案されている。中でも、PtMn系は耐食性と熱的安定性が良く、NiOや $\alpha\text{-Fe}_2\text{O}_3$ 等の酸化物を磁化回転抑制層として用いたスピバルブ膜は、MR比が15%以上と飛躍的に大きいものが得られている。

【0005】

【発明が解決しようとする課題】しかしながら、NiO膜の場合はブロッキング温度が十分高くなく、NiOスピバルブ膜の熱的安定性には問題がある。

【0006】また、 $\alpha\text{-Fe}_2\text{O}_3$ スピバルブ膜も金属磁性膜のピン止め効果が弱い欠点があり、特にデュアルスピバルブ構造や固定層上に $\alpha\text{-Fe}_2\text{O}_3$ を付けた構造のスピバルブとした場合、上部の $\alpha\text{-Fe}_2\text{O}_3$ 膜においてこの傾向が顕著である。PtMn系は、熱的安定性に優れるもののNiOや $\alpha\text{-Fe}_2\text{O}_3$ ほど大きなMR比が得られない課題がある。従って、PtMn系のような熱的安定性と、NiOや $\alpha\text{-Fe}_2\text{O}_3$ 系のような大きなMR比の両立が一つの課題であった。

【0007】更により磁気抵抗効果を示す金属膜部の総膜厚が薄く、より大きなMR比を示す磁気抵抗効果素子を得るのが課題であった。

【0008】本発明の目的は、熱的安定性と高MR比とを有する磁気抵抗効果素子とその製造方法、磁気抵抗効果型ヘッド、磁気記録装置、磁気抵抗効果メモリ素子を提供することにある。

【0009】

【課題を解決するための手段】以上の課題を解決するために本発明では以下に詳細を述べる固定層に金属磁性膜と酸化物磁性膜との積層膜を用いることを特長とする。この構成とすることにより、より大きなMR比を得るのが可能となり、例えばこの構成で磁化回転抑制層にPtMn系等を用いれば、熱的安定性と高MR比の両立が可能となる。

【0010】本発明に係る磁気抵抗効果素子は、外部磁界により容易に磁化回転する自由層と、第1非磁性層と、該第1非磁性層に対して該自由層の反対側に設けられ、該外部磁界により容易には磁化回転しない第1固定層とを含み、該第1固定層と該自由層との少なくとも一方は、該第1非磁性層と接する第1金属磁性膜と、第1酸化物磁性膜とを含み、そのことにより上記目的が達成される。

【0011】前記第1固定層は、前記第1金属磁性膜と、前記第1酸化物磁性膜とを含んでもよい。

【0012】前記自由層に対して前記第1非磁性層の反対側に設けられる第2非磁性層と、該第2非磁性層に対して該自由層の反対側に設けられ、該外部磁界により容易には磁化回転しない第2固定層とをさらに含んでもよい。

【0013】前記自由層は、前記第1金属磁性膜と、前記第1酸化物磁性膜とを含んでもよい。

【0014】前記自由層に対して前記第1非磁性層の反対側に設けられ、平坦性の良好な酸化物非磁性膜をさらに含んでもよい。

【0015】前記第1酸化物磁性膜と磁気的に結合する磁化回転抑制層をさらに含んでもよい。

【0016】前記自由層は、前記酸化物磁性膜に対して前記第1金属磁性膜の反対側に設けられる第2金属磁性膜をさらに含んでもよい。

【0017】前記第1固定層と磁気的に結合するが磁化回転抑制層をさらに含んでもよい。

【0018】前記第1固定層は、前記第1酸化物磁性膜に対して前記第1金属磁性膜の反対側に設けられる第2金属磁性膜をさらに含んでもよい。

【0019】前記第1固定層は、前記第1酸化物磁性膜に対して前記第1金属磁性膜の反対側に設けられる第2金属磁性膜と、第3金属磁性膜と、該第2金属磁性膜と該第3金属磁性膜とを反強磁性的に交換結合する交換結合用非磁性膜とをさらに含んでもよい。

【0020】前記第1固定層は、前記第1酸化物磁性膜に対して前記第1金属磁性膜の反対側に設けられる非磁性膜と、該非磁性膜を介して該第1酸化物磁性膜と磁気的に交換結合する第2酸化物磁性膜をさらに含んでもよい。

【0021】前記第1酸化物磁性膜は、Fe元素を含有してもよい。

【0022】前記第1酸化物磁性膜は、Fe元素とX元素とを含有してもよい。ただしXはAl, Si, B, Nから成る群より選ばれる1種もしくは2種以上の元素である。

【0023】前記第1酸化物磁性膜は、 MFe_2O_4 (MはFe, Co, Niから選ばれる1種もしくは2種以上の元素)を主成分としてもよい。

【0024】前記第1酸化物磁性膜は、 Fe_3O_4 を主成分としてもよい。

【0025】前記第1酸化物磁性膜は、 CoFe_2O_4 を主成分としてもよい。

【0026】前記磁化回転抑制層は、P-Mn系 (PはPt, Ni, Pd, Ir, Rh, Ru, Crから選ばれる1種もしくは2種以上の元素)合金より成ってもよい。

【0027】前記磁化回転抑制層は、 $\alpha\text{-Fe}_2\text{O}_3$ 、NiOのいずれか、もしくはこれらの積層膜から成ってもよい。

【0028】前記該磁化回転抑制層は、 $(\text{AB})_2\text{O}_x$ 層から成ることを特長とする請求項6記載の磁気抵抗効果素子。ただし $(\text{AB})_2\text{O}_x$ とはAとB元素を足したものとO元素との比が2:Xであることを示し、Oは酸素原子2.8<X<3.2の条件を満足し、かつ原子A、B、Oのイオン半径をそれぞれRa, Rb, Roとして次式

$$t = (\text{Ra} + \text{Ro}) / (\sqrt{2} \cdot (\text{Rb} + \text{Ro}))$$

で定義されるものが0.8<t<0.97であることを満足するもの

である。

【0029】前記 $(AB)_2O_x$ 層のBがFeを主成分とする遷移金属元素であってもよい。

【0030】前記 $(AB)_2O_x$ 層のAが(Y,Laを含む)希土類元素から選ばれる1種もしくは2種以上の元素であってもよい。

【0031】前記第1酸化物磁性膜は、前記第1金属磁性膜の酸化物であってもよい。

【0032】前記第1金属磁性膜は、Co-Fe合金からなってもよい。

【0033】特に該自由層は、非磁性膜と、前記非磁性膜を介して反強磁性的に交換結合した、膜厚または飽和磁化の異なる2つの金属磁性膜とを含んでもよい。

【0034】前記磁気抵抗効果素子の膜面の上下に配置される電極をさらに含み、電流を前記膜面に垂直に流してもよい。

【0035】本発明に係る磁気抵抗効果型ヘッドは、本発明に係る磁気抵抗効果素子と、シールド部とを具備し、そのことにより上記目的が達成される。

【0036】本発明に係る他の磁気抵抗効果型ヘッドは、本発明に係る磁気抵抗効果素子と、検知すべき磁界を前記磁気抵抗素子に導入するヨークとを具備し、そのことにより上記目的が達成される。

【0037】本発明に係る磁気記録装置は、本発明に係る磁気抵抗効果型ヘッドと、記録媒体と該磁気抵抗効果型ヘッドとのトラッキングを制御するサーボ部と、該磁気抵抗効果型ヘッドが該記録媒体に記録再生する信号を処理する信号処理部とを備え、そのことにより上記目的が達成される。

【0038】本発明に係る磁気抵抗効果メモリ素子は、本発明に係る磁気抵抗効果素子と、該磁気抵抗効果素子から情報を読み出すための情報読出用導体線と、該情報を記録するための情報記録用導体線とを具備し、そのことにより上記目的が達成される。

【0039】本発明に係る磁気抵抗効果素子の製造方法は、本発明に係る磁気抵抗効果素子の製造方法であって、前記第1酸化物磁性膜を、酸化物ターゲットを用いてスパッタ法により形成する第1工程を包含し、そのことにより上記目的が達成される。

【0040】前記酸化物ターゲットは Fe_3O_4 を含んでもよい。

【0041】前記第1工程は、不活性ガスと酸素ガスとを用いてスパッタ法により前記第1酸化物磁性膜を形成する第2工程を包含してもよい。

【0042】前記第1工程は、不活性ガスと酸素ガスとを用いてスパッタ法により前記第1酸化物磁性膜を形成する第2工程を包含してもよい。

【0043】前記酸化物ターゲットは $CoFe_2O_4$ を含んでもよい。

【0044】本発明に係る他の磁気抵抗効果素子の製造

方法は、基板上に直接または下地層を介して、外部磁界により容易に磁化回転する自由層、非磁性層、外部磁界により容易には磁化回転しない固定層の金属磁性膜を順次積層する第1の工程と、該固定層の該金属磁性膜の表面を酸化させる第2の工程と、該金属磁性膜の表面上に酸化物磁性膜を形成する第3の工程と、該酸化物磁性膜の上に磁化回転抑制層を更に形成する第4の工程とを包含し、そのことにより上記目的が達成される。

【0045】前記第2の工程は、プラズマ酸化法を含んでもよい。

【0046】前記第2の工程は、酸素ラジカル源から発生した酸素ラジカルにより、前記金属磁性膜の前記表面を酸化する工程を含んでもよい。

【0047】前記第2の工程は、自然酸化法を含んでもよい。

【0048】前記第2の工程は、イオン源より発生した酸素イオンを用いて前記金属磁性膜の前記表面を酸化する工程を含んでもよい。

【0049】本発明に係るさらに他の磁気抵抗効果素子の製造方法は、基板上に直接または下地層を介して、外部磁界により容易に磁化回転する自由層、非磁性層、外部磁界により容易には磁化回転しない固定層の第1金属磁性膜を順次積層する第1の工程と、該固定層の酸化物磁性膜を反応性スパッタリング法により形成する第2の工程と、該酸化物磁性膜その上に該固定層の第2金属磁性膜を形成する第3の工程と、該第2金属磁性膜上に磁化回転抑制層を更に形成する第4の工程とを包含し、そのことにより上記目的が達成される。

【0050】

【発明の実施の形態】本発明のスピバルブ膜を構成するには図1に示したように、磁性膜(自由層5)/非磁性層4/[金属磁性膜32/酸化物磁性膜31](固定層3)/磁化回転抑制層2(ピンニング層)なる構成とし、非磁性層4と固定層3の金属磁性膜32が接し、磁化回転抑制層2と固定層3の酸化物磁性膜31が接する構成とする。

【0051】又、図2に示したように上記の非磁性層4と接しない自由層5の面に酸化物非磁性層6を付けても良い。この時自由層5と酸化物非磁性層6の界面は平坦であることが重要である。

【0052】更に図3に示したように磁化回転抑制層2(ピンニング層)/[酸化物磁性膜31/金属磁性膜32](固定層3)/非磁性層4/磁性膜(自由層5)/非磁性層4/[金属磁性膜32/酸化物磁性膜31](固定層3)/磁化回転抑制層2(ピンニング層)なる構成としても良い。

【0053】また本発明は図5Aに示したように自由層5Aが該非磁性層4と接する金属磁性膜51と酸化物磁性膜52の積層膜より構成しても良い。図5Aの固定層3Dには金属磁性膜と酸化物磁性膜を積層したものを

いても良い。

【0054】特に自由層5Bが図6に示したように[金属磁性膜51/酸化物磁性膜52/金属磁性膜51]より構成されても良い。

【0055】これら図5A、6に示したものの固定層は図7に示すような磁化回転抑制層2と接する構成としても良い。更にその固定層3Dを図1、2、あるいは後述する図4と同様の構成としても良いし、図8に示したように固定層を[金属磁性膜32/酸化物磁性膜31/金属磁性膜32]で構成しても良い。

【0056】なお図7、8の自由層を図5Aのような構成としても良い。

【0057】これら酸化物磁性膜としてはFe元素を含有するものが望ましい。例えばFe元素とX元素を含有するFe-X(Xは原子%で4~30%)系のものが軟磁気特性と高抵抗を兼ね備えている。ただしXはAl, Si, B, Nから成る群より選ばれる1種もしくは2種以上の元素である。成膜法としてはFe-Al, Fe-Si, Fe-B等をターゲットに用いて、酸素や窒素を用いた反応スパッタ法によりFeAlO, FeSiO, FeBO, FeAlON, FeSiON, FeBON, FeAlSiO, FeAlSiON等が形成出来る。以下に述べるMFe₂O₄系よりは抵抗が低い成膜条件や組成で抵抗の調整が可能である利点がある。

【0058】又上記酸化物磁性膜はMFe₂O₄(MはFe, Co, Niから選ばれる1種もしくは2種以上の元素)を主成分として構成することが望ましい。

【0059】この場合の酸化物磁性膜にはFe₃O₄を主成分として構成すれば上記のFe-X系より更に高抵抗となり、CoFe₂O₄を主成分とするものを用いれば更に高抵抗となり、この場合は硬質磁気特性を示すため固定層の一部として使用するのに適している。

【0060】上記ピンニング層はP-Mn系(PはPt, Ni, Pd, Ir, Rh, Ru, Crから選ばれる1種もしくは2種以上の元素)合金より成ることを望ましいが、 α -Fe₂O₃、NiOのいずれか、もしくはこれらの積層膜で構成されても良いし、(AB)₂O_x膜で構成されても良い。ただし(AB)₂O_xとはAとB元素を足したものとO元素との比が2:Xであることを示し、Oは酸素原子で2.8<X<3.2の条件を満足し、かつ原子A、B、Oのイオン半径をそれぞれR_a, R_b, R_oとして次式

$$t = (R_a + R_o) / (\sqrt{2} \cdot (R_b + R_o))$$

で定義されるtが0.8<t<0.97であることを満足するものである。

【0061】この場合(AB)₂O_x層のBはFeを主成分とする遷移金属元素であることが望ましく、Aは(Y, Laを含む)希土類元素から選ばれる1種もしくは2種以上の元素であることが望ましい。

【0062】これらの膜はスパッタ法等により基板上に

形成されるが、図1に示したようにピンニング層が下にくる場合はピンニング層として α -Fe₂O₃、NiO、(AB)₂O_x膜を用いることが望ましく、図1とは上下逆の構成でピンニング層が上に来る場合にはP-Mn系が望ましい。ただしPt-Mn系は上下どちらにも対応可能である。

【0063】図2についても同様であり、図3においては上下のピンニング層を別々に望ましいものを用いても良い。

【0064】特殊な場合として図4に示したように該固定層3Aが該非磁性層4と接する金属磁性膜32と、非磁性膜33を介して磁気的に交換結合をしている酸化物磁性膜31の積層膜より構成されても良い。

【0065】更には以上述べた図1~2、図4、図5A、図8を適当に組み合わせた図9~13のような構成としても良い。

【0066】図9は図8の構成の上下を逆とし、自由層5は図1~3の構成のように単層としたものであるが、自由層5の軟磁気特性を向上させるために下地層7を設けたものである。

【0067】図10は図8の構成を基本として、自由層5に単層膜を用い、上部に酸化物非磁性膜6を設けた構成のものである。又磁化回転抑制層2の特性を向上させるために下地層7を設けている。

【0068】図11Aは図10の構成を基本として、磁化回転抑制層2と接する金属磁性膜32ともう一つの金属磁性膜32を非磁性膜33を介して、図4の固定層3Aのように磁気的に交換結合させているものである。通常、この交換結合は反強磁性的のものを用い、これにより磁化回転抑制層2のピンニング効果を高める効果が得られる。この場合は図4とは異なり、金属磁性膜32を用いている。なおこの場合は自由層5の上には図10と異なり酸化物非磁性膜は無いが、上部にはキャップとして酸化膜を設けても良いし、金属の保護膜を設けても良い。

【0069】以上述べた磁気抵抗効果素子では通常膜面に電流を流すが、酸化物磁性層を有するため、特に電極を素子の膜面の上下に配置し、電流を膜面に垂直に流す構成とすることが可能である。

【0070】本発明の磁気抵抗効果型ヘッドは、図14A、14B、図15に示したように本発明の磁気抵抗効果素子9に、更にシールド10、15を具備してなるものと、検知すべき磁界を磁気抵抗効果素子9に導入すべく設けられた軟磁性体を用いて構成されるヨーク16を具備してなることを特長とする2種類のものである。図14Aはハードバイアス部12を有し、図14Bは反強磁性バイアス部12Aを有する構成となっている。

【0071】図では膜面内を電流が流れる構成としたが、図14A、14Bのリード部13をMR素子9の膜面上下につけ、上部シールド15及び下部シールド10

とつなげば膜面垂直に電流が流れる構成となり、狭ギャップ化に対して有利な構造となる(ただしこの場合ハードバイアス部12と素子9を絶縁するか、ハードバイアス部12を絶縁物で構成する必要がある。)

図16は以上述べた磁気ヘッドを用いて作製される磁気記録装置1600の構成図である。磁気記録装置は情報を記録するディスク1604、記録・再生する磁気ヘッド部1601、信号処理部1603、ヘッドとディスクのトラッキングをするサーボ部1602より成り立っている。本発明の磁気ヘッドを用いたこの磁気記録装置では従来より高密度記録が可能である。

【0072】以上に述べた磁気抵抗効果素子に、更に情報を読み出すためのセンス線23と、情報を記録するためのワード線22とを具備すれば図17に示すような磁気抵抗効果メモリ素子1700となり、これらの素子をマトリックス状に配置すれば所謂MRAM(磁気抵抗ランダムアクセスメモリ)が構成される。

【0073】以下本発明の磁気抵抗効果素子、磁気抵抗効果型ヘッド、磁気抵抗メモリ素子を図面に基づいて詳細に説明する。

【0074】図1に本発明の磁気抵抗効果素子100の構成を示す断面図の一例を示す。図1では、基板1上に、磁化回転抑制層2、固定層3(酸化物磁性膜31/金属磁性膜32)、非磁性層4、自由層5が順次積層されている。固定層3の酸化物磁性膜31の磁化は、磁化回転抑制層2による交換バイアス磁界によりピン止めされており、酸化物磁性膜33と金属磁性膜32は強磁性的に結合しているため、金属磁性膜32の磁化も酸化物磁性膜33の磁化と同じ方向にピン止めされている。一方の磁性体である自由層5は、非磁性層4により、固定層3より磁氣的に分離されているので、外部からの磁界により比較的自由に動くことができる。一般的に二つの磁性層の磁化方向が反平行の場合は電子は[磁性層/非磁性層]界面で散乱され素子の抵抗は高くなる。

【0075】これに対して磁化方向が同じ場合は界面での電子の散乱は少なく素子の抵抗は低くなる。従って、固定層3と自由層5の磁化の角度が相対的に変化し、それによって、素子の電気抵抗が変化する。磁気抵抗センサーとしては、図1の自由層5に電極を付けて電流を流し、外部からの磁界により生じた抵抗変化を電気信号として読みとることができる。又図1の基板1の上の構造(磁化回転抑制層2~自由層5)を上下逆にしても良い。この場合は電極は上部の磁化回転抑制層2と酸化物磁性膜33を取り除き、金属磁性膜32と接する必要がある。なお図1には磁化回転抑制層2を示したが、固定層3自体が容易に磁化回転しない保磁力の大きな硬質磁性膜であれば、磁化回転抑制層2は不要である。

【0076】なお、図1において磁化回転抑制層2は必ずしも必要ではない。例えば酸化物磁性膜31が保磁力の大きな硬質磁性膜であれば、これと金属磁性膜32が

磁氣的に結合して、磁化回転抑制層2無しでも固定層としての役割を十分果たし、磁気抵抗効果素子が構成出来る。

【0077】本発明者らは、磁気抵抗を支配する要因が[磁性層/非磁性層]界面でほぼ決まり、磁性層が金属膜である場合はその膜厚が増加するとシャント効果によりRと ΔR が減少することに着目して、図1に示したように非磁性層4と固定層3との界面は金属/金属界面とし、残りの固定層の部分は酸化物磁性膜としてシャント効果によるRと ΔR の低減を改善している。これにより素子全体の抵抗Rを高くでき、素子の出力は抵抗変化量 ΔR と素子電流Iの積： $I \times \Delta R$ に比例するため、その出力の向上が可能となる。これに対して、図で酸化物磁性膜31が無い場合、スピバルブ膜の抵抗Rは小さくなり、特に磁化回転抑制層2が金属膜である場合このRの減少は顕著であり、MR比(磁気抵抗率)： $\Delta R/R$ が同じ値を出せたとしても出力は減少する。なお酸化物磁性膜31と金属磁性膜32の界面は凹凸が0.5nm以下の平坦性を有することが望ましい。平坦性が悪いと磁性層の磁化が平行の場合でも抵抗が高くなりMR比が低下するからである。

【0078】一般的に磁化回転抑制層が金属膜より酸化膜の場合の方が大きなMR比が得られるが、ピン止めされる磁性膜(固定層)が金属膜の場合はそのピン止め効果が弱い欠点がある。上述のように磁化回転抑制層と接する固定層を酸化物磁性膜とすることによりこの課題は改善される。

【0079】図2は更に自由層5の表面に平坦性に優れた酸化物非磁性膜6を設けて表面での電子を鏡面反射させ、これにより磁性層の磁化が平行な場合の抵抗をより低くして大きなMR比を得ようとする磁気抵抗効果素子200である。この場合も酸化物非磁性膜6と自由層5の界面は、凹凸が0.5nm以下の平坦性を有することが望ましく、そうでないと十分な反射効果が得られない。

【0080】なお自由層5の軟磁気特性を劣化させないものであれば上記の酸化膜は平坦性の良好な酸化物磁性膜でも良い。又自由層5の表面に電子を鏡面反射する金属反射膜即ちAg、Au膜を設けても良い。この場合は金属反射膜は厚すぎるとシャント効果でMR比が低下するので、10nm以下、望ましくは3nm以下とするのがよい。

【0081】この場合も金属反射膜と自由層5の界面は、凹凸が0.5nm以下の平坦性を有することが望ましく、そうでない場合には十分な反射効果は得られない。更にこの金属反射膜の上に上述の酸化物非磁性膜を設けても良い。又図2に示した構造を上下逆にしても良い。

【0082】上下逆にした場合は電極は上部の磁化回転抑制層2と酸化物磁性膜31を取り除き、金属磁性膜3

2と接する必要がある。

【0083】図3は本発明を用いたデュアルスピンバルブ構造の磁気抵抗効果素子300で、一般的に図1の構造に比べて、電子が磁氣的散乱を受ける〔磁性層/非磁性層〕界面が増加するためより大きなMR比が得られるのがその特長である。従来の場合、酸化物磁性膜31が無かったため、素子全体の抵抗Rは減少し、 ΔR はさほど増加せず出力的には大きな改善とならない課題があったが、図3に示した構造とすることにより、2つの酸化物磁性膜31で挟まれた中を主に電流は流れるためRの減少は少なく、かつMR比は増大するため大きな出力を得ることが可能となる。この場合は電極は上部の磁化回転抑制層2と酸化物磁性膜31を取り除き、金属磁性膜32と接する必要がある。

【0084】図4は特殊な場合として固定層3Aが非磁性層4と接する金属磁性膜32と、非磁性膜33を介して磁氣的に交換結合をしている二つの酸化物磁性膜31の積層膜より構成されている磁気抵抗効果素子400である。図4において酸化物磁性膜31は非磁性膜33を介して磁氣的に交換結合し、外部磁界により容易には磁化回転しない。これと金属磁性膜32が磁氣的に結合することにより全体として固定層3Aを構成している。更に酸化物磁性膜31と該非磁性膜33との間に新たな金属磁性膜を設けて、非磁性膜33を介した二つの酸化物磁性膜31の間の交換結合を強化しても良い。

【0085】なお図には示さなかったが更に基板1と酸化物磁性膜31の間に図1～図3と同様に磁化回転抑制層2を設けても良い。

【0086】上述したものは固定層に酸化物磁性膜を用いたものであるが図5～図8に示したように自由層に酸化物磁性膜を用いても良い。

【0087】図5Aにおいては自由層5Aは非磁性層4と接する金属磁性膜51と酸化物磁性膜52より構成されており、自由層がすべて金属磁性膜の場合より大きなMR比が得られ、かつ素子500A全体の金属部の総膜厚を低減出来る長所がある。ただしこの場合酸化物磁性膜52は軟磁性を示すものが望ましい。また図では固定層3は単層膜で示したが、図5Bに示したように金属磁性膜32と酸化物磁性膜31との積層膜でも良い。

【0088】図6の素子600も同様の効果が得られる長所の他、酸化物磁性膜52を2nm以下に薄くすれば、その酸化物磁性膜52の軟磁気特性は図5の場合ほど厳密に必要ではない。

【0089】いずれの場合も酸化物磁性膜52は抵抗が高いことが望ましい。

【0090】図7は固定層3が磁化回転抑制層2によりピンニングされているタイプの構成例で、また図8は特に固定層3Bが〔金属磁性膜32/酸化物磁性膜31/金属磁性膜32〕より成ることを特徴とするものである。図7の場合は磁化回転抑制層2が酸化物の方が大き

なMR比が得られ、図8の場合は固定層3Bの中央の酸化物磁性膜31の抵抗が高い方が大きなMR比が得られる。

【0091】図9は図8の構成の上下を逆とし、自由層は図1～図3の構成のように単層としたものであるが、自由層5の軟磁気特性を向上させるために下地層7を設けたものである。

【0092】図10は図8の構成を基本として、自由層に単層膜を用い、上部に酸化物非磁性膜6を設けた構成のものである。又磁化回転抑制層2の特性を向上させるために下地層7を設けている。この場合は上部に設けた酸化物非磁性膜6と自由層5の界面を平坦とすることにより、MR比が大きくなる効果が得られる。

【0093】図11Aは図10の構成を基本として、磁化回転抑制層2と接する磁性層（金属磁性膜32）とも一つの磁性層（金属磁性膜32）を非磁性膜33を介して、図4の固定層3Aのように磁氣的に交換結合させてものであるが、この場合は図4とは異なり、金属磁性膜32を用いている。非磁性膜33の膜厚を適当な値（例えばRuを用いてその膜厚を0.6～0.8nm）とすることにより、この交換結合を反強磁性的とすることが可能である。これにより磁化回転抑制層2のピンニング効果を高める効果が得られる。

【0094】また反強磁性的結合とすることにより、この磁気抵抗効果素子1100をスピンバルブヘッドに用いた場合、固定層3C全体による自由層5へのバイアス磁界を低減出来る効果が得られる。なおこの場合は自由層5の上には図10と異なり酸化物非磁性膜6は無いが、上部にはキャップとして酸化膜を設けても良いし、金属の保護膜を設けても良い。

【0095】図12は特に自由層5Cが非磁性膜53を介して反強磁的に交換結合した、膜厚または飽和磁化の異なる2層の強磁性膜（金属磁性膜51）からなるものを用いた素子である。非磁性膜53を介して二つの強磁性膜は反平行となっており、自由層5C全体での磁化は二つの磁性膜の膜厚をそれぞれ d_1 、 d_2 とし、飽和磁化をそれぞれ M_{s1} 、 M_{s2} とすると $M_{s1} \cdot d_1 - M_{s2} \cdot d_2$ となり、全体での反磁界係数を小さくすることが出来る。一般に素子幅が小さくなると反磁界係数が大きくなり、磁気抵抗素子やヘッドの場合はその感度が劣化し、メモリ素子の場合は磁化反転の際のワード線の電流を増加させる要因となるが、この構造とすることによりその課題が解決される。

【0096】図13は図6と図12の素子構造を融合させたもので、自由層5Dの磁性膜の一方に酸化物磁性膜52を挿入し、更に大きなMR比を得ようとするものである。

【0097】磁化回転抑制層2としては金属膜としては不規則合金系のIr-Mn, Rh-Mn, Ru-Mn, Cr-Pt-Mn等があり、磁界中で成膜することによ

磁性膜と交換結合させることができ工程が簡便となる利点がある。これらの膜を用いて素子を形成する場合は図1、2とは上下逆の構成とすることが望ましく、図3では上の磁化回転抑制層2に用いることが望ましい。一方規則合金系のNi-Mn, Pt-(Pd)-Mn等は規則化のための熱処理が必要であるが、熱的安定性に優れている。一般的にはこれらも磁気抵抗効果素子に用いる場合は図1、2とは上下逆の構成が望ましく、図3では上の磁化回転抑制層2に用いることが望ましい。なおPt-Mn系は上下どちらでも使用出来き、ピンニング効果も大きく、かつ熱的にも安定なため望ましい特長を有するが、これら金属膜を磁化回転抑制層2に用いた素子は大きなMR比が得られない欠点があった。本発明はこの欠点を補い磁化回転抑制層2にこれら金属系を用いても大きなMR比を得ることが可能である。

【0098】磁化回転抑制層2として酸化膜を用いる場合は上述したように $(AB)_2O_x$ 、NiO、 $\alpha-Fe_2O_3$ 等の酸化膜があり、これらを用いると大きなMR比が得られ、本発明の構成とすることにより、より大きなMR比が得られる。NiOは熱的安定性にやや課題があるので $\alpha-Fe_2O_3$ と積層構造にするとより望ましい。 $(AB)_2O_x$ 膜はそれ自体の耐熱性に優れるが成膜時に基板加熱が必要である。 $(AB)_2O_x$ においてはAはイオン半径の大きい元素で、La, Pr, Nd, Sm, Y等の希土類元素が望ましく、Bはイオン半径が小さい遷移金属が望ましく、ピン止め効果が高温まである磁化回転抑制層としては特にFeが望ましい。

【0099】図に示した磁気抵抗素子の自由層5としては、Ni-Co-Fe合金が適している。Ni-Co-Fe膜の原子組成比としては、 $Ni_xCo_yFe_z$

$$0.6 \leq x \leq 0.9$$

$$0 \leq y \leq 0.4$$

$$0 \leq z \leq 0.3$$

のNi-richの軟磁性膜、もしくは、 $Ni_{x'}Co_{y'}Fe_{z'}$

$$0 \leq x' \leq 0.4$$

$$0.2 \leq y' \leq 0.95$$

$$0 \leq z' \leq 0.5$$

のCo-rich膜を用いるのが望ましい。これらの組成の膜はセンサーやMRヘッド用として要求される低磁歪特性(1×10^{-5})を有する。

【0100】自由層5の膜厚としては1nm以上10nm以下がよい。膜厚が厚いとシャント効果でMR比が低下するが、薄すぎると軟磁気特性が劣化する。より望ましくは2nm以上7nm以下がよい。

【0101】固定層の金属磁性膜32としては、CoまたはCo-Fe, Ni-Fe, Ni-Fe-Co合金等の材料が優れている。特にCoまたはCo-Fe合金が大きなMR比を得るのに良いので非磁性層4との界面にはCo-richを用いることが望ましい。

【0102】固定層の酸化物磁性膜31としては MFe_2O_4 (MはFe, Co, Niから選ばれる1種もしくは2種以上の元素)が望ましい。これらは比較的高温まで強磁性を示し、Fe-richに比べCo, Ni-richは極めて抵抗が高い。又Co-richは磁気異方性が大きい特長があるので、これらの組成比の調整により所望の特性のものが得られる。軟磁気特性や飽和磁化の観点からは Fe_3O_4 を主成分とするものが望ましい。

【0103】又金属磁性膜32と酸化物磁性膜31より成る固定層3、3A、3B、3Cには、磁気異方性が大きく保磁力が大きい $CoFe_2O_4$ を主成分とするものが望ましい。

【0104】酸化物磁性膜31の作製法としては、膜厚を0.1nmのオーダーで精密にコントロールする場合はターゲットに酸化物を用い、スパッタ法により成膜することが望ましい。

【0105】上記の場合、例えば Fe_3O_4 、あるいは $CoFe_2O_4$ を主成分とするターゲットを用いてArガス等の不活性ガスによりスパッタすれば、 Fe_3O_4 や $CoFe_2O_4$ 膜の精密な膜厚コントロールが可能であり、又スパッタ室内に酸素ガスを流す必要がないためスパッタ室を高真空に保つことが可能である。

【0106】時として MFe_2O_4 をターゲットに用いても、出来る膜中のO(酸素)が、少なくなる場合や、ターゲットからOが抜けて、膜中のOが少なくなる場合があるが、この場合はスパッタガスに適量(通常は不活性スパッタガスとの分圧比で10%以下が望ましい)の酸素ガスを加えてスパッタすれば、所望の膜組成が得られる。

【0107】固定層3の別の材料としては、金属磁性膜32とその酸化物を酸化物磁性膜31として用いることができる。この場合、酸化物磁性膜として新たにスパッタリングターゲットを用意する必要がなく、生産が容易となる。特に金属磁性膜32として、Co-Fe膜を用いた場合、Co-Fe-O膜は良好な酸化物磁性膜31となる。

【0108】このとき、酸化物磁性膜31の形成方法としては、種々の方法がある。まず一つはあらかじめ金属磁性膜32を形成しておいて、その後、金属磁性膜32の表面を酸化させる方法である。金属磁性膜32の表面を酸化させる方法は、プラズマ酸化法、自然酸化法、ラジカルガンを用いる方法、イオンガンを用いる方法などがある。プラズマ酸化法とは、真空チャンバー中で酸素ガスを流しながら、金属膜表面と電極との間にrfまたはDCの電位差を与え、膜表面と電極との間にプラズマを発生させ、そのプラズマによって金属膜表面を酸化させるものである。金属膜表面のダメージも大きいが、比較的高抵抗の酸化膜が形成される。

【0109】自然酸化法は、金属膜を一度大気に暴露するという方法もあるが、大気中では、湿度が一定でない

等の問題もあり、より望ましくは、真空チャンバーに大気圧以下の圧力に酸素ガスを導入し、金属膜の表面を酸化する方法がよい。

【0110】また、ラジカルガンを用いる方法は、ガンの内部の放電によって発生した酸素ラジカルを、金属膜表面に照射して酸化させる方法で、比較的金属膜にダメージ少なく表面だけ酸化させるのに有効な方法である。

【0111】また、ラジカルではなくイオンを用いても膜表面を酸化することができる。イオン源としては、熱フィラメントを用いるカウフマン型、ECR放電を利用するタイプなどいろいろあるが、いずれも本発明では有効である。この場合、イオンガンで発生した酸素イオンを加速電圧を印可して、金属表面にぶつける。加速電圧としては、あまり高すぎると金属膜のダメージが大きくなるのでせいぜい500V以下、望ましくは200V以下とするのがよい。

【0112】固定層3の全体の膜厚は1nm以上10nm以下がよい。

【0113】また、MR比を更に大きくするために、強磁性体層(固定層3または自由層5)と非磁性層4の界面に界面磁性層を挿入するのも有効である。自由層5は軟磁気特性が必要なためNi-richが良いが、非磁性層4と接する自由層5の界面磁性層にはCo-richを用い、その他はNi-richとするれば軟磁気特性を損なうことなく高MR比とすることが可能である。又図3の様な構造では自由層5の中心には上記のNi-richを用い非磁性層4との界面にはCo-richを用いるのが望ましい。自由層5の界面磁性層の膜厚が厚いと、軟磁気特性が劣化しMR比の磁界感度が低下するので、界面磁性層の膜厚は2nm以下、望ましくは1.8nm以下とする必要がある。またこの界面磁性層が有効に働くためには、少なくとも0.2nm以上の膜厚は必要であり、望ましくは0.8nm以上の膜厚がよい。界面磁性層の材料としては、CoまたはCo高濃度のCo-Fe合金が優れている。

【0114】図4や図11の非磁性膜33及び図12、13の非磁性膜53には磁性層間の交換結合を生じやすい非磁性金属膜が望ましく、Cu, Ag, Auでも良いが、界面の熱的安定性からはRu, Rh, Ir, Re等のほうがより望ましく、特にRuが優れている。更図4で、酸化物磁性膜31と該非磁性膜33との間に設ける場合の金属磁性膜としては、Co-richの金属磁性膜が望ましい。この金属磁性膜の挿入により非磁性膜33を介した二つの酸化物磁性膜31の間の交換結合を強化することが可能である。

【0115】自由層5と固定層3の間の非磁性層4としては、Cu, Ag, Au, Ruなどがあるが、特にCuが優れている。非磁性層4の膜厚としては、磁性層間の相互作用を弱くするために少なくとも0.9nm以上は必要である。また非磁性層4が厚くなるとMR比が低下

してしまうので膜厚は10nm以下、望ましくは3nm以下とするべきである。又この非磁性層4の膜厚が3nm以下の場合は図1～図3の構成において、基板1からこの非磁性層4までの各層の平坦性は重要で、平坦性が悪いと、非磁性層4で磁氣的に分離されているはずの二つの磁性層(金属磁性膜32と自由層5)の間に磁氣的結合が生じてMR比の劣化と感度の低下が生ずる。従って磁性層/非磁性層の界面の凹凸は0.5nm以下であることが望ましい。

【0116】基板1としては、ガラス、MgO、Si、Al₂O₃-TiC基板等表面の比較的平滑なものを用いる。MRヘッドを作製する場合には、Al₂O₃-TiC基板が適している。

【0117】なお以上述べた各層の構成方法としては、スパッタリング法が適している。スパッタリング法としてはDCスパッタリング法、RFスパッタリング法、イオンビームスパッタリング法などがあるが、いずれの方法でも本発明の磁気抵抗効果素子を作製できる。

【0118】以上述べたような本発明の磁気抵抗効果素子を用いて、磁気抵抗効果型ヘッドを構成することができる。図14AにMRヘッドの一例としてハード膜バイアス型のMRヘッド1400Aの構成の一例を示す。図14AではMR素子9は上部および下部のシールドギャップ11、14に挟まれるように構成されている。シールドギャップ材としては、Al₂O₃、SiO₂、AlN等の絶縁膜が使われる。

【0119】上部および下部シールド10、15としてはNi-Fe(-Co)、Co-Nb-Zr、Fe-Ta-N合金などの軟磁性膜が使われる。Ni-Fe(-Co)系はメッキ法で作製でき、Co-Nb-Zr系は耐食性に優れ、異方性の制御性が良い。Fe-Ta-N系は高温熱処理に強く、上述の(AB)₂O_x系のように基板温度を高温で成膜する必要のある磁化回転抑制層を使用する場合有効である。

【0120】MR素子9の磁区制御には、Co-Pt合金等のハード膜より成るハードバイアス部12のバイアス磁界を用いる。MR素子9はシールドギャップ11、14によってシールド10、15等と絶縁されており、リード部13を介して電流を流すことにより、MR素子9の抵抗変化を読みとる。

【0121】将来のハードディスクドライブの高密度化を考慮すると、記録波長を短くする必要性があり、そのためには図14Aに示したシールド間の距離dを短くする必要がある。そのためには図14Aから明らかな様に、MR素子9を薄くする必要がある、少なくとも20nm以下とするのが望ましい。酸化物の磁化回転抑制層2は、絶縁膜であるので、実質的にMR素子9と言うよりは下部シールドギャップ11の一部ととらえることができ、この目的に適した構造といえる。

【0122】またMR素子9においては、自由層の磁化

回転時にバルクハウゼンノイズの発生を押さえるために、図1、2、3、4の自由層5の磁化容易軸は、検知すべき信号磁界方向に垂直となるように、固定層3の磁化容易軸は検知すべき磁界方向と平行になるように構成されているのがよい。

【0123】図14Aに示したものはハードバイアス部12を有するものであるが、図14Bに示すものはこれに代わって反強磁性バイアス部12Aを有するものである。高密度化にともないシールドギャップは狭くなり、ハードバイアス部12からの磁界がシールド部に吸収されMR素子9の自由層5へのバイアス磁界が弱くなる問題があるが、この反強磁性バイアス部12Aを有する構造ではこの課題が解決される長所がある。ただしこの場合はMR素子9の反強磁性膜と反強磁性バイアス部12Aの反強磁性膜を異なるものとした方が素子1400Bは形成しやすく、例えばMR素子9にはPtMn系を反強磁性バイアス部12AにはIrMn系等を使用すれば良い。

【0124】なお、以上は従来の横型GMRヘッドについて説明したが、本発明は縦型のGMRヘッドに対しても有効である。横型GMRヘッドが検知する磁界に対して電流方向が垂直であるのに対して、縦型GMRヘッドは磁界に対して平行に電流を流すのを特徴とする。

【0125】本発明の磁気ヘッドの一例として図14A、14Bのシールド型とは別なヨーク型ヘッド1500を図15に示す。図15において16はMR素子9に検知すべき信号磁界をガイドする軟磁性膜で構成されたヨークで、通常このヨークは導電性の金属磁性膜を用いるため、MR素子9とショートしないように絶縁膜17が設けられる。又このヘッド1500はヨーク16を用いるため感度では図14A、14Bのタイプのヘッド1400A、1400Bより劣るが、図14A、14Bのようにシールドギャップ中にMR素子9を置く必要がないため超狭ギャップ化では有利である。

【0126】これらの磁気ヘッド1400A、1400B、1500は再生感度に優れているため、これら磁気ヘッドを用いてHDD等の磁気記録装置をすると、40 Gb/inch²を越えるような高密度な磁気記録装置が可能となる。

【0127】図17は本発明の磁気抵抗効果素子を用いたメモリ素子の一例である。メモリ素子1700は本発明の〔自由層/非磁性層/固定層〕を有する磁気抵抗効果素子9、磁気抵抗効果素子9とは絶縁された情報記録用導体線（ワード線）22、磁気抵抗効果素子9と電極21によりつながれた情報読出用導体線（センス線）23を有する。図では本発明の磁気抵抗効果素子9の膜面の上下に電極21を有する構造のものを示しているが磁気抵抗効果素子9の左右に電極を有する構造としても良い。又固定層3の下に磁化回転抑制層を付けても良い。

【0128】図においてワード線22に電流を流し、こ

れにより発生する磁界により、磁気抵抗効果素子9の自由層5の磁化を反転して情報を書き込みを行う。再生は再度ワード線22に電流を流して自由層5の磁化を反転し、その時の抵抗変化をセンス線23により情報の読み出しを行う。この場合は固定層3の磁化反転を行わず、自由層5の磁化反転のみを行い、固定層3との磁化の方向が平行か反平行かで磁気抵抗効果素子9の抵抗が異なることより“1”、“0”状態の識別を行う。

【0129】上記の場合は情報読出の際に情報が消される破壊読出であるが、ワード線22に電流を流して、固定層3も自由層5も磁化反転を起こす磁界を発生させ、固定層3に情報を記録し、読み出しはワード線22に上記より弱い電流を流して、固定層3の磁化反転は起こさず自由層5の磁化反転のみ起こす磁界を発生して自由層5の磁化反転のみを起こし、これに伴う抵抗変化により“1”、“0”状態を識別すれば非破壊読み出しが可能である。ただしこの場合固定層3用と自由層5用の異なる反転磁界の設定が必要なため、動作はやや複雑となる。

【0130】これら磁気抵抗メモリ素子1700を複数個マトリックス状に配置し、ワード線を各MR素子9上で直交する配置として、ワード線22から発生する合成磁界によりMR素子9への情報の書き込み、読み出しを行えば、所謂MRAMが構成される。このMRAMは従来の半導体DRAMと異なり、不揮発性で、ソフトエラーも無く次世代固体メモリとして有望である。

【0131】

【実施例】本発明の磁気抵抗効果素子および磁気抵抗効果型ヘッド、磁気抵抗効果メモリ素子について以下具体的な実施例を用いて説明する。

【0132】（実施例1）多元スパッタリング装置を用いて図1に示した構成から磁化回転抑制層2の無い磁気抵抗効果素子を作製した。基板1にはSiを用い、非磁性層4用としてはCuを、自由層5用にはNi_{0.68}Fe_{0.20}Co_{0.12}を主に用い、固定層3の金属磁性膜32用としてCo_{0.9}Fe_{0.1}の合金ターゲットを用いた。又固定層3の酸化物磁性膜31用にはCoFe₂O₄を用いた。真空チャンバー内を1×10⁻⁸Torr以下まで排気した後、Arガスを約0.8mTorrになるように流しながら、ガラス基板上に、スパッタリング法を用いて、下記の実施例サンプル1Aの構成の磁気抵抗効果素子を作製した。又比較のためCoFe₂O₄を用いない従来例試料も作製した。

【0133】実施例サンプル1A NiFeCo(5)/Cu(2)/CoFe(2)/CoFe₂O₄(5)

（カッコ内は各層の膜厚をnm単位で示したものである）

このようにして作製した磁気抵抗効果素子のMR特性を室温で最高200kA/mの磁界を印可して、直流4端

子法で評価した。その結果MR比が16%という高い値を得ることに成功した。一方 CoFe_2O_4 を用いない従来例試料は特性のばらつきが大きく、MR比も10%を超えるものは得られなかった。以下MR比は%の値で示すこととする。

【0134】(実施例2) 多元スパッタリング装置を用いて図1に示した構成の磁気抵抗効果素子100を作製した。基板1にはSiを用い、磁化回転抑制層2用のターゲットには焼結した NiO 、 $\alpha\text{-Fe}_2\text{O}_3$ 、 ABO_3 ($\text{A}=\text{La}$; $\text{B}=\text{Fe}$) を、又合金ターゲットとして $\text{Pt}_{0.5}\text{Mn}_{0.5}$ 、 $\text{Ir}_{0.2}\text{Mn}_{0.8}$ を用いた。

【0135】非磁性層41用としてはCuを、自由層5用には $\text{Ni}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ を主に用い、自由層5の界面磁性膜用と固定層3の金属磁性膜32用として $\text{Co}_{0.9}\text{Fe}_{0.1}$ の合金ターゲットを用いた。又固定層3の酸化物磁性膜31用には Fe_3O_4 を用いた。真空チャンバー内を $1 \times 10^{-8} \text{ Torr}$ 以下まで排気した後、Arガスを約0.8mTorrになるように流しながら、ガラス基板上に、スパッタリング法を用いて、下記の構成の磁気抵抗効果素子を作製した。又比較のため Fe_3O_4 を用いない試料も作製した(従来例サンプルA~D)

従来例サンプルA $\text{NiFeCo}(3)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(2.5)/\text{PtMn}(20)$

従来例サンプルB $\text{NiFeCo}(3)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(2.5)/\text{IrMn}(15)$

従来例サンプルC $\text{NiO}(10)/\alpha\text{-Fe}_2\text{O}_3(20)/\text{CoFe}(2.5)/\text{Cu}(2)/\text{CoFe}(1)/\text{NiFeCo}(3)$

従来例サンプルD $\text{LaFeO}_3(40)/\text{CoFe}(2.5)/\text{Cu}(2)/\text{CoFe}(1)/\text{NiFeCo}(3)$

実施例サンプル1 $\text{NiFeCo}(3)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(1)/\text{Fe}_3\text{O}_4(1.5)/\text{PtMn}(20)$

実施例サンプル2 $\text{NiFeCo}(3)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(1)/\text{Fe}_3\text{O}_4(1.5)/\text{NiFeCo}(3)$

実施例サンプル3 $\text{NiO}(10)/\alpha\text{-Fe}_2\text{O}_3(20)/\text{Fe}_3\text{O}_4(1.5)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(1)/\text{NiFeCo}(3)$

実施例サンプル4 $\text{LaFeO}_3(40)/\text{Fe}_3\text{O}_4(1.5)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(1)/\text{NiFeCo}(3)$

ただし従来例サンプルA、B、実施例サンプル1、2は図1とは上下逆の構造である。また上記試料では $\text{NiFeCo}(3)/\text{CoFe}(1)$ が自由層5に対応し、従来例サンプルA~Dでは $\text{CoFe}(2.5)$ が固定層3に対応し、実施例サンプル1~4では $\text{CoFe}(1)/$

$\text{Fe}_3\text{O}_4(1.5)$ が固定層3に対応する。

【0136】このようにして作製した磁気抵抗効果素子のMR特性を室温で最高200kA/mの磁界を印可して、直流4端子法で評価した。素子のピン止め磁界を H_p とし、測定結果を(表1)に示した。

【0137】

【表1】

試料	MR比	H_p (kA/m)
従来例サンプル A	8	80
従来例サンプル B	11	40
従来例サンプル C	16	20
従来例サンプル D	12	45
実施例サンプル 1	13	80
実施例サンプル 2	14	40
実施例サンプル 3	19	40
実施例サンプル 4	15	50

【0138】(表1)に示した実験結果より従来例サンプルA~Dが本発明構造とすることによりMR比が増加し、酸化物磁化回転抑制層2を用いたものの H_p が改善されていることがわかる。

【0139】(実施例3) 実施例1と同様に、多元スパッタリング装置を用いて図2に示した構造の磁気抵抗効果素子200を作製した。酸化物非磁性膜6は Al_2O_3 ターゲットを用い、Arと O_2 の混合ガスによる反応スパッタにより Al_2O_3 膜を作製した。図2に示すような磁気抵抗効果素子200を作製した。

【0140】実施例サンプル5 $\text{PtMn}(20)/\text{Fe}_3\text{O}_4(1.5)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(1)/\text{NiFeCo}(3)/\text{Al}_2\text{O}_3(2)$

実施例サンプル6 $\text{Al}_2\text{O}_3(2)/\text{NiFeCo}(3)/\text{CoFe}(1)/\text{Cu}(2)/\text{CoFe}(1)/\text{Fe}_3\text{O}_4(1.5)/\text{IrMn}(15)$

ただし実施例サンプル6は図2とは逆の構造となっている。このようにして作製した磁気抵抗効果素子のMR特性を室温で最高200kA/mの磁界を印可して、直流4端子法で評価した。素子のピン止め磁界を H_p とし、測定結果を表2に示した。

【0141】

【表2】

試料	MR比	H_p (kA/m)
実施例サンプル 5	15	80
実施例サンプル 6	16	40

【0142】(表2)の結果と表1の実施例サンプル1、2を比較するとMR比が改善されていることがわかる。

【0143】(実施例4) 多元スパッタリング装置を用いて図5B及び図7に示した構成の磁気抵抗効果素子5

00A、700を作製した。基板1にはSiを用い、ターゲットとして非磁性層4用としてはCuを、自由層5A、5Bの金属磁性膜51用には $\text{Ni}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ を、酸化物磁性膜52用には Fe_3O_4 を用いた。

【0144】図5Bの固定層3用には $\text{Co}_{0.9}\text{Fe}_{0.1}$ と CoFe_2O_4 の積層膜を用い、図7の固定層3D用に $\text{Co}_{0.9}\text{Fe}_{0.1}$ を、また磁化回転抑制層2用に $\alpha\text{-Fe}_2\text{O}_3$ を用いた。

【0145】真空チャンバー内を $1 \times 10^{-8}\text{Torr}$ 以下まで排気した後、Arガスを約0.8mTorrになるように流しながら、ガラス基板上に、スパッタリング法を用いて、下記の構成の磁気抵抗効果素子500B、700を作製した。

【0146】実施例サンプル7 CoFe_2O_4 (50) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Cu (2) / $\text{Ni}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ (4) / Fe_3O_4 (1)

実施例サンプル8 $\alpha\text{-Fe}_2\text{O}_3$ (50) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Cu (2) / $\text{Ni}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ (2) / Fe_3O_4 (1) / $\text{Ni}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ (3)

このようにして作製した磁気抵抗効果素子500B、700のMR特性を室温で最高200kA/mの磁界を印可して、直流4端子法で評価した。素子のピン止め磁界を H_p とし、測定結果を(表3)に示した。

【0147】

【表3】

試料	MR比	H_p (kA/m)
実施例サンプル 7	12	35
実施例サンプル 8	13	40

【0148】(表3)に示した H_p の特性を更に改善するには固定層3をRu等の非磁性膜を介して交換結合した磁性膜を用いることが有効である。

【0149】この場合酸化物磁性膜31の膜厚を低減することも可能となる。又上記実施例では感度の観点から自由層5Bに NiFeCo 膜を用いているが、 CoFe を用いれば更に大きなMR比が得られる。

【0150】この観点から更にターゲットにRuを用いて以下の構成の磁気抵抗効果素子を同様に作製した。

【0151】実施例サンプル9 $\alpha\text{-Fe}_2\text{O}_3$ (30) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Ru (0.7) / CoFe (2) / Cu (2) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (4) / Fe_3O_4 (1)

このようにして作製した磁気抵抗効果素子のMR特性を室温で最高200kA/mの磁界を印可して、直流4端子法で評価した。素子のピン止め磁界を H_p とし、測定結果を(表4)に示した。

【0152】

【表4】

試料	MR比	H_p (kA/m)
実施例サンプル 9	16	60

【0153】このようにMR比も H_p も更に改善できることがわかった。

【0154】(実施例5)多元スパッタリング装置を用いて図7及び図8に示した構成の磁気抵抗効果素子700、800を作製した。基板1にはSiを用い、ターゲットとして非磁性層4用としてはCuを、自由層5Bの金属磁性膜51用には $\text{Ni}_{0.8}\text{Fe}_{0.2}$ と $\text{Co}_{0.9}\text{Fe}_{0.1}$ を、酸化物磁性膜52用には Fe_3O_4 を用いた。図7の固定層3D用には $\text{Co}_{0.9}\text{Fe}_{0.1}$ を、磁化回転抑制層2には $\alpha\text{-Fe}_2\text{O}_3$ を用い、図8の固定層3B用に $\text{Co}_{0.9}\text{Fe}_{0.1}$ と Fe_3O_4 を、磁化回転抑制層2用にPtMnを、またPtMnと基板1の間のバッファ層としてTaを用いた。真空チャンバー内を $1 \times 10^{-8}\text{Torr}$ 以下まで排気した後、Arガスを約0.8mTorrになるように流しながら、ガラス基板上に、スパッタリング法を用いて、下記の構成の磁気抵抗効果素子を作製した。

【0155】実施例サンプル10 $\alpha\text{-Fe}_2\text{O}_3$ (50) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Cu (2) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Fe_3O_4 (1) / $\text{Ni}_{0.8}\text{Fe}_{0.2}$ (3)

実施例サンプル11 Ta (5) / PtMn (15) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Fe_3O_4 (1) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Cu (2) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (5)

実施例サンプル12 Ta (5) / PtMn (15) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Fe_3O_4 (1) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Cu (2) / $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2) / Fe_3O_4 (1) / $\text{Ni}_{0.8}\text{Fe}_{0.2}$ (3)

このようにして作製した磁気抵抗効果素子のMR特性を室温で最高200kA/mの磁界を印可して、直流4端子法で評価した。素子のピン止め磁界を H_p とし、測定結果を(表5)に示した。

【0156】

【表5】

試料	MR比	H_p (kA/m)
実施例サンプル 10	20	40
実施例サンプル 11	17	50
実施例サンプル 12	19	45

【0157】(実施例6)多元スパッタリング装置を用い図4に示した構造の磁気抵抗効果素子400を作製した。

【0158】基板1にはSiを用い、非磁性層4用としてはCuを、自由層5用には $\text{Ni}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ を主に用い、固定層3Aの金属磁性膜32用として $\text{Co}_{0.9}\text{Fe}_{0.1}$ の合金ターゲットを用いた。又固定層3Aの酸化物磁性膜31用には Fe_3O_4 を用いた。真空チャン

バー内を 1×10^{-8} Torr以下まで排気した後、Arガスを約0.8mTorrになるように流しながら、ガラス基板上に、スパッタリング法を用いて、下記の構成の磁気抵抗効果素子を作製した。

【0159】実施例サンプル13 NiFeCo(4)/Cu(2)/CoFe(2)/Fe₃O₄(2)/Ru(0.7)/Fe₃O₄(3)

実施例サンプル14 NiFeCo(4)/Cu(2)/CoFe(2)/Fe₃O₄(2)/CoFe(2)/Ru(0.7)/CoFe(2)/Fe₃O₄(3)

このようにして作製した磁気抵抗効果素子のMR特性を室温で最高200kA/mの磁界を印可して、直流4端子法で評価した。測定結果を(表6)に示した。

【0160】

【表6】

試料	MR比	Hp(kA/m)
実施例サンプル 13	13	20
実施例サンプル 14	13	30

【0161】大きなMR比が両者で、また実施例サンプル14ではより大きなHpが得られることがわかった。

【0162】実施例サンプル13、14のFe₃O₄(3)に更に磁化回転抑制層としてPtMnを付加することによりHpは、それぞれ約60、80kA/mと更に大きくなることがわかった。

【0163】(実施例7)次に本発明の実施例サンプル1、5、10の磁気抵抗効果素子をMR素子9として用いて、図14Aに示すようなMRヘッド1400Aを構成して、特性を評価した。この場合、基板としてはAl₂O₃-TiC基板を用い、シールド10、15材にはNi_{0.8}Fe_{0.2}合金を用い、シールドギャップ11、14にはAl₂O₃を用いた。

【0164】またハードバイアス部12にはCo-Pt合金を用い、リード部13をAuで構成した。

【0165】また、自由層5の磁化容易方向が検知すべき信号磁界方向と垂直になるように、固定層3の磁化容易軸の方向が検知すべき信号磁界方向と平行になるように磁性膜に異方性を付与した。この方法は、磁気抵抗効果素子を作成後、まず、磁界中280℃で熱処理して、固定層3の容易方向を規定した後、更に、200℃で熱処理して、自由層5の容易軸を規定して行った。

【0166】これらのヘッドに、センス電流として直流電流を流し、約3kA/mの交流信号磁界を印加してヘッドの出力を評価し、本発明のMR素子を用いたMRヘッドの出力を、従来例サンプルAの磁気抵抗効果素子をMR素子部9に用いて同様に試作したヘッドの出力と比較した。その結果を以下に示す。

【0167】

【表7】

試作ヘッド	MR素子部	相対出力(dB)
従来例 H-A	A	0
実施例 H-1	1	+4
実施例 H-5	5	+5
実施例 H-10	10	+6

【0168】この様に本発明磁気ヘッドは従来のものに比較して大きな出力が得られることがわかった。

【0169】(実施例8)実施例1と同様の方法で、図3に示すデュアル構造の磁気抵抗素子300を作成した。

【0170】実施例サンプル15 PtMn(20)/Fe₃O₄(1.5)/CoFe(1)/Cu(2)/CoFe(1)/NiFeCo(3)/CoFe(1)/Cu(2)/CoFe(1)/Fe₃O₄(1.5)/PtMn(20)

実施例サンプル16 NiO(10)/α-Fe₂O₃(20)/Fe₃O₄(1.5)/CoFe(1)/Cu(2)/CoFe(1)/NiFeCo(3)/CoFe(1)/Cu(2)/CoFe(1)/Fe₃O₄(1.5)/IrMn(15)

以上の磁気抵抗効果素子に関して、実施例1と同様の方法でMR効果を測定した。

【0171】その結果を表8に示す。

【0172】

【表8】

試料	MR比(%)	Hp(kA/m)
実施例サンプル 15	22	80
実施例サンプル 16	28	40

【0173】表より極めて大きなMR比が得られることがわかる。

【0174】(実施例9)上記の実施例サンプル15のMR素子を用いて図15に示したヨーク型ヘッド1500を作製した。この場合図15の絶縁膜17にはプラズマ酸化法で作製した厚さ2nmのAl-O超薄膜を用いた。又ヨーク16には高透磁率のCoNbZr系アモルファス合金膜を用いた。このようにして作製したヘッドの出力と実施例1の表1の従来例サンプルAのMR素子を用いたヘッド出力を比較したところ約+6dBの出力アップが実現されることがわかった。

【0175】(実施例10)実施例1と同様のスパッタリング装置を用いて、図9に示す磁気抵抗効果素子900を作成した。この場合、基板1には表面に約100nmの熱酸化膜を有するSiを用い、下地層7としてTa、自由層5および固定層3Bの金属磁性膜32としてCo_{0.9}Fe_{0.1}、非磁性層4としてCu、磁化回転抑制層2として、Pt_{0.5}Mn_{0.5}膜を用いた。真空チャンバー内を 1×10^{-8} Torr以下となるまで排気した後、排気しながらArガスを約0.8mTorrになるよう

に流量を調節した。まず基板1上にTa (5nm) 膜を形成した後、第1の工程として、自由層 $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2nm)、非磁性層Cu (2nm)、金属磁性膜 $3\text{Co}_{0.9}\text{Fe}_{0.1}$ (3nm) をスパッタ法で順次形成した。次に、第2の工程として、いったんスパッタ放電を停止させ、Arガスに加えて、約1/8の酸素ガスを流し、ラジカルガンに約100Wの電力を投入して、酸素ラジカルを発生させ、それを金属膜の表面に照射して、金属磁性膜の表面約1nmを酸化させて酸化物磁性膜31を形成した。

【0176】次に、第3の工程として、いったんガスフローを停止して放電を停止した後、再びArガスを導入して金属磁性膜32として $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2nm) をスパッタリング法で形成した。

【0177】さらに、第4の工程として、磁化回転抑制層2として $\text{Pt}_{0.5}\text{Mn}_{0.5}$ (20nm) 膜をスパッタリング法で形成した。最後に表面に酸化物非磁性膜6としてTa酸化膜を形成した。このあと、試料は更に真空中で1kOeの磁界を印加しながら、260℃の温度に3時間保持した。また、従来例サンプルEとして、上記第2の工程がない以外は全く実施例サンプル17と同様に作成した。

【0178】実施例サンプル17 Ta (5)/ $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2)/Cu (2)/ $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2)/Co-Fe-O (1)/ $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2)/ $\text{Pt}_{0.5}\text{Mn}_{0.5}$ (20)/Ta-O (3) (Co-Fe-Oの膜厚は酸化する前で示してある)

従来例サンプルE Ta (5)/ $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2)/Cu (2)/ $\text{Co}_{0.9}\text{Fe}_{0.1}$ (5)/ $\text{Pt}_{0.5}\text{Mn}_{0.5}$ (20)/Ta-O (3)

なお、以上は金属磁性膜32を酸化させる方法として、ラジカルガンを用いる方法を用いた実施例サンプル17について説明したが、その他は全く同様にして酸化物を作成する手段だけ他の方法を用いた膜も作成した。

【0179】自然酸化法を用いた場合には、第1の工程までは全く実施例サンプル17と同様の方法で作成し、その後、チャンバー内をいったん排気した後、第2の工程としてチャンバー内が約20Torrになるまで酸素ガスを導入して、適当な時間保持して実施例サンプル17と同様、 $\text{Co}_{0.9}\text{Fe}_{0.1}$ 膜の表面1nmを酸化させた。次に真空チャンバーを再び 1×10^{-8} Torr以下となるまで排気して、第3、第4の工程、熱処理を経て、実施例サンプル17と全く同じ構成の実施例サンプル18を作成した。

【0180】プラズマ酸化法を用いる場合には、実施例サンプル17と同様の方法で作成し、その後、第2の工程としてチャンバー内をいったん排気した後、3mTorr程度になるまで酸素ガスを導入し、基板ホルダー側に $0.01\text{W}/\text{cm}^2$ のrf電力を印加して金属磁性膜表面を酸化させた。次に真空チャンバーを再び 1×10^{-8} Torr以下となるまで排気して、第3、第4の工程、熱処理を経て、実施例サンプル17と全く同じ構成の実施例サンプル19を作成した。

【0181】また、イオンガンを用いる方法としては、イオンガンとしてECRプラズマを使用したイオンガンを用いた。第1の工程までは全く実施例サンプル17と同様の方法で作成し、その後、チャンバー内をいったん排気した後、第2の工程として、イオンガンに2GHzのマイクロ波を導入し、酸素ガスを4sccm、Arガスを0.5sccm流して、イオンガン中にプラズマを発生させた。このプラズマから約50Vの加速電圧で酸素ガスを引きだして、金属磁性膜表面に照射した。次に真空チャンバーを再び 1×10^{-8} Torr以下となるまで排気して、第3、第4の工程、熱処理を経て、実施例サンプル17と全く同じ構成の実施例サンプル20を作成した。

【0182】次に、酸化物磁性膜を形成する方法として反応性スパッタリング法を用い、その他は実施例サンプル17と同じ方法で作成した膜も作成した。この場合は、第1の工程で金属磁性膜 $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2nm) を作成した後、チャンバー内に酸素ガスとArガスを8:2の割合で0.8mTorrになるまで導入して $\text{Co}_{0.9}\text{Fe}_{0.1}$ (2nm) をスパッタリングしてCo-Fe-O膜をほぼ実施例サンプル17と同じ厚さになるように形成した。その後は実施例サンプル17と同様に第3、第4の工程、熱処理を経て、実施例サンプル17と全く同じ構成の実施例サンプル21を作成した。

【0183】このようにして作成した本発明の磁気抵抗効果素子を、室温で400kA/mの磁界を印可して磁気抵抗効果を評価した。その結果を表9に示す。

【0184】

【表9】

試料	MR比(%)	Hp (kA/m)
実施例サンプル 17	13	78
実施例サンプル 18	13.5	60
実施例サンプル 19	12	75
実施例サンプル 20	12.8	70
実施例サンプル 21	13.3	68
従来例サンプル E	8	75

【0185】(表9)からわかるように、本発明の実施例サンプル17~21は従来例サンプルEに比べてHpでは遜色なくMR比が大きいことが分かる。

【0186】(実施例11) 実施例10と同様のスパッタリング装置を用いて、図10に示す磁気抵抗効果素子1000を作成した。図10は、図9で自由層5/非磁性層4/固定層3B/磁化回転抑制層2の積層順を逆にした以外は同じである。

【0187】また、作成方法に関しても、工程の順番が

変わるだけで、図9と同様の方法で作成できる。本実施例の場合、基板1として熱酸化膜付きのSi、自由層5として $\text{Ni}_{0.8}\text{Fe}_{0.2}/\text{Co}$ 積層膜、固定層3Bとして $\text{Co}_{0.8}\text{Fe}_{0.2}/\text{Co-Fe-O}/\text{Co}_{0.8}\text{Fe}_{0.2}$ 膜、磁化回転抑制層2として $\text{Pt}_{0.5}\text{Mn}_{0.5}$ 膜を用いて、以下の構成の磁気抵抗効果素子を作成した。なお、この場合、実施例サンプル17と同様にラジカルガンを使う方法で、 Co-Fe-O 膜を形成した。このようにして作成した実施例サンプル22と比較のために酸化物磁性膜31のない従来例サンプルFを実施例10と同様の方法で評価した。

【0188】その結果を表10に示す。

【0189】実施例サンプル22 $\text{Ta}(5)/\text{Pt}_{0.5}\text{Mn}_{0.5}(15)/\text{Co}_{0.8}\text{Fe}_{0.2}(2)/\text{Co-Fe-O}(1)/\text{Co}_{0.8}\text{Fe}_{0.2}(2)/\text{Cu}(2)/\text{Co}(0.5)/\text{Ni}_{0.8}\text{Fe}_{0.2}(3)/\text{Ta-O}(3)$

(Co-Fe-O の膜厚は酸化する前で示してある)

従来例サンプルF $\text{Ta}(5)/\text{Pt}_{0.5}\text{Mn}_{0.5}(15)/\text{Co}_{0.8}\text{Fe}_{0.2}(5)/\text{Cu}(2)/\text{Co}(0.5)/\text{Ni}_{0.8}\text{Fe}_{0.2}(3)/\text{Ta-O}(3)$

【0190】

【表10】

試料	MR比(%)	Hp (kA/m)
実施例サンプル 22	15	67
従来例サンプル F	9	66

【0191】(表10)からわかるように、本発明の実施例サンプル22は従来例サンプルFに比べてMR比が大きいことが分かる。

【0192】(実施例12) 実施例10と同様のスパッタリング装置を用いて、図11Aに示す磁気抵抗効果素子1100Aを作成した。図11Aは、固定層3Cがいわゆる積層フェリ(synthetic antiferromagnet)構造をしている場合である。図11Aで、非磁性膜33には通常Ruが用いられる。非磁性膜33が0.4nm-1nmの膜厚の時、これに接した金属磁性膜32に反強磁性的な交換結合が生じる。この交換結合磁界は非常に強いので、結局固定層3Cの反転磁界は非常に大きくなる。図11Aの磁気抵抗効果素子1100Aの構成は、基本的に図9に比べて非磁性膜33が増えるだけなので、その製造方法も工程が一部増加するだけで、本発明は有効である。本実施例の場合、基板1として熱酸化膜付きのSi、自由層5として $\text{Ni}_{0.8}\text{Fe}_{0.2}/\text{Co}$ 積層膜、固定層3Cとして $\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Co-Fe-O}(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)$ 膜、磁化回転抑制層2として $\text{Ir}_{0.2}\text{Mn}_{0.8}$ 膜または $\alpha\text{-Fe}_2\text{O}_3$ 膜を用いて、以下の構成の磁気抵抗効果素子を作成した。

【0193】なお、この場合、実施例サンプル17と同様にラジカルガンを使う方法で、 Co-Fe-O 膜を形

成した。このようにして作成した実施例サンプル23、24と比較のために酸化物磁性膜32のない従来例サンプルGを実施例10と同様の方法で評価した。その結果を表11に示す。

【0194】実施例サンプル23 $\text{Ta}(3)/\text{Ni}_{0.8}\text{Fe}_{0.2}(5)/\text{Ir}_{0.2}\text{Mn}_{0.8}(10)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Co-Fe-O}(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}(0.5)/\text{Ni}_{0.8}\text{Fe}_{0.2}(3)/\text{Ta-O}(3)$

(Co-Fe-O の膜厚は酸化する前で示してある)

実施例サンプル24 $\alpha\text{-Fe}_2\text{O}_3(20)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Co-Fe-O}(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}(0.5)/\text{Ni}_{0.8}\text{Fe}_{0.2}(3)/\text{Ta-O}(3)$

従来例サンプルG $\text{Ta}(3)/\text{Ni}_{0.8}\text{Fe}_{0.2}(5)/\text{Ir}_{0.2}\text{Mn}_{0.8}(10)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}(0.5)/\text{Ni}_{0.8}\text{Fe}_{0.2}(3)/\text{Ta-O}(3)$

【0195】

【表11】

試料	MR比(%)	Hp (kA/m)
実施例サンプル 23	15	100
実施例サンプル 24	18	60
従来例サンプル G	9	95

【0196】(表11)からわかるように、本発明の実施例サンプル23、24は従来例サンプルGに比べてMR比が大きいことが分かる。また、磁化回転抑制層2に $\alpha\text{-Fe}_2\text{O}_3$ 膜を用いた場合には、Hpはやや小さくなるが、より大きなMR比が得られる。

【0197】(実施例13) 次に図10に示した構成の磁気抵抗効果素子1000を、実施例1と同様の方法で、作成した。ただし、この場合自由層5に非磁性層4(この場合Ru)を介して反強磁性的に交換結合した膜厚または飽和磁化の異なる2つの強磁性層(積層フェリ自由層)を用いる。積層フェリ自由層は自由層の膜厚を、実質的に2つの自由層の膜厚(磁化)の差に下げる効果があり、ヘッドを作成した場合高感度化に効果がある。本実施例では自由層5の強磁性膜として $\text{Co}_{0.9}\text{Fe}_{0.1}$ 膜を用いた。作成した膜の構成を以下に示す。この場合酸化物磁性膜31とし Fe_3O_4 膜を用い、固定層3Bの金属磁性膜32に $\text{Co}_{0.9}\text{Fe}_{0.1}(2)$ 膜、磁化反転抑制層2として $\text{Pt}_{0.5}\text{Mn}_{0.5}(20)$ 膜、非磁性層4としてCuを用いた。

【0198】実施例サンプル25 $\text{Ta}(5)/\text{Pt}_{0.5}\text{Mn}_{0.5}(20)/\text{Co}_{0.9}\text{Fe}_{0.1}(1)/\text{Fe}_3\text{O}_4(1.5)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}$

$0.9\text{Fe}_{0.1}(2)/\text{Fe}_3\text{O}_4(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(3)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(4)/\text{Ta-O}(3)$

実施例サンプル26 $\text{Ta}(5)/\text{Pt}_{0.5}\text{Mn}_{0.5}(20)/\text{Co}_{0.9}\text{Fe}_{0.1}(1)/\text{Fe}_3\text{O}_4(1.5)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Fe}_3\text{O}_4(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(3)/\text{Ta-O}(3)$

従来例サンプルH $\text{Ta}(5)/\text{Pt}_{0.5}\text{Mn}_{0.5}(20)/\text{Co}_{0.9}\text{Fe}_{0.1}(3)/\text{Cu}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(5)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(4)/\text{Ta-O}(3)$

MR素子9として用いて、図14Aに示すようなMRヘッド1400Aを構成して、特性を評価した。この場合、基板としては $\text{Al}_2\text{O}_3\text{-TiC}$ 基板を用い、シールド10、15材には $\text{Ni}_{0.8}\text{Fe}_{0.2}$ 合金を用い、シールドギャップ11、14には Al_2O_3 を用いた。

【0199】またハードバイアス部12には Co-Pt 合金を用い、リード部13を Au で構成した。

【0200】また、自由層5の磁化容易方向が検知すべき信号磁界方向と垂直になるように、固定層3の磁化容易軸の方向が検知すべき信号磁界方向と平行になるように磁性膜に異方性を付与した。この方法は、磁気抵抗効果素子を作成後、まず、磁界中280℃で熱処理して、固定層3の容易方向を規定した後、更に、200℃で熱処理して、自由層5の容易軸を規定して行った。

【0201】これらのヘッドに、センス電流として直流電流を流し、約3kA/mの交流信号磁界を印加してヘッドの出力を評価し、本発明のMR素子を用いたMRヘッドの出力を、従来例サンプルAの磁気抵抗効果素子をMR素子部9に用いて同様に試作したヘッドの出力と比較した。その結果を以下に示す。

【0202】

【表12】

試作ヘッド	MR素子部	相対出力 (dB)
従来例 H-H	H	0
実施例 H-25	15	+6
実施例 H-26	16	+7

【0203】この様に本発明磁気ヘッドは従来のものに比較して大きな出力が得られることがわかった。

【0204】(実施例14)次に図11Aに示した構成の磁気抵抗効果素子1100Aを、実施例1と同様の方法で、作成した。本実施例では自由層5の強磁性膜として $\text{Co}_{0.9}\text{Fe}_{0.1}$ 膜を用いた。作成した膜の構成を以下に示す。この場合酸化物磁性膜31とし Fe_3O_4 膜を用い、金属磁性膜32に $\text{Co}_{0.9}\text{Fe}_{0.1}$ 膜、磁化反転抑制層2として $\text{Pt}_{0.5}\text{Mn}_{0.5}$ 膜、非磁性層4として Cu を用い、交換結合用非磁性膜33として Ru を、保護膜用

として Ta を用いた。作製した膜の構成は以下のとおりである。

【0205】実施例サンプル27 $\text{Ta}(5)/\text{Pt}_{0.5}\text{Mn}_{0.5}(15)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Fe}_3\text{O}_4(1.2)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ta-O}(3)$

実施例サンプル28 $\text{Ta}(3)/\text{Pt}_{0.5}\text{Mn}_{0.5}(15)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Fe}_3\text{O}_4(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ta-O}(3)$

従来例サンプルI $\text{Ta}(5)/\text{Pt}_{0.5}\text{Mn}_{0.5}(15)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ta-O}(3)$

このようにして作製したMR素子を用いて、実施例13と同様にして磁気ヘッドを作製した。

【0206】これらのヘッドに、センス電流として直流電流を流し、約3kA/mの交流信号磁界を印加して両ヘッドの出力を評価し、本発明のMR素子を用いたMRヘッドの出力を、従来例サンプルIの磁気抵抗効果素子をMR素子9に用いて同様に試作したヘッドの出力と比較した。その結果を(表13)に示す。

【0207】

【表13】

試作ヘッド	MR素子部	相対出力 (dB)
従来例 H-I	I	0
実施例 H-27	17	+8
実施例 H-28	18	+8

【0208】このように本発明磁気ヘッドは従来のものに比較して大きな出力が得られることがわかった。

【0209】この磁気ヘッド1400A、1400B、1500を用いて図16に示した構成のHDDドライブ1600を試作したところ、20Gb/inch²以上の記録密度が達成可能なることがわかった。

【0210】(実施例15)次に実施例13と14の構造を併せ持つ図11Aに示した構成の磁気抵抗効果素子1100Aを作成した。本実施例では自由層5の強磁性膜として $\text{Ni}_{0.68}\text{Fe}_{0.2}\text{Co}_{0.12}$ 膜を用い、酸化物磁性膜31としては $\text{Fe}_{0.8}\text{Al}_{0.2}$ 、 $\text{Fe}_{0.8}\text{Si}_{0.2}$ をターゲットに用いて反応スパッタで FeAlO 、 FeSiO 膜としたものを用い、金属磁性膜32に $\text{Co}_{0.9}\text{Fe}_{0.1}$ 膜、磁化反転抑制層2として $\text{Pt}_{0.5}\text{Mn}_{0.5}$ 膜、非磁性層4として Cu 、交換結合用非磁性膜33として Ru 、保護膜用として Ta を用いた。作成した膜の構成を以下に示す。

【0211】実施例サンプル29 $\text{Ta}(3)/\text{Pt}$

$0.5\text{Mn}_{0.5}(15)/\text{Co}_{0.9}\text{Fe}_{0.1}(3)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{FeAlO}(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2.2)/\text{NiFeCo}(3)/\text{Ru}(0.7)/\text{NiFeCo}(2)/\text{Ta}(3)$

実施例サンプル30 $\text{Ta}(3)/\text{Pt}_{0.5}\text{Mn}_{0.5}(15)/\text{Co}_{0.9}\text{Fe}_{0.1}(3)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{FeSiO}(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2.2)/\text{NiFeCo}(3)/\text{Ru}(0.7)/\text{NiFeCo}(2)/\text{Ta}(3)$

図17を参照して、この様にして作成した磁気抵抗効果素子を $0.5\mu\text{m}$ 角にパターンニングして、膜の左右に Cu/Pt から成る電極21を付けセンス線23を構成し、これらを Al_2O_3 で絶縁した後、その上に Cu より構成されるワード線22を設けて磁気抵抗効果メモリ素子1700を作成した。

【0212】ワード線22に電流を流して $\text{NiFeCo}/\text{Ru}/\text{NiFeCo}$ より成る自由層5を磁化反転して情報を書き込んだ。次にワード線22に同じ方向に電流を流し、センス線23の抵抗変化を測定しても変化は観測されなかったが、電流を逆方向に流したところセンス線23には明確な抵抗変化が観測された。このように本発明の磁気抵抗素子9を用いてメモリ素子1700が構成出来ることがわかった。

【0213】(実施例16) 次に自由層5Dにも酸化物磁性膜52を挿入した図13に示した構成の磁気抵抗効果素子1300を基板上に電極用の Cu/Pt 膜を付けた後作成した。本実施例では自由層5Dの金属磁性膜51として $\text{Ni}_{0.68}\text{Fe}_{0.2}\text{Co}_{0.12}$ 膜を用い、酸化物磁性膜52には Fe_3O_4 膜、金属磁性膜32に $\text{Co}_{0.9}\text{Fe}_{0.1}$ 膜、磁化反転抑制層2として $\text{Pt}_{0.5}\text{Mn}_{0.5}$ 膜、非磁性層4として Cu を用い、交換結合用非磁性膜33として Ru を、保護膜用として Ta を、上部電極用として Pt を用いた。作成した膜の構成を以下に示す。

【0214】実施例サンプル31 $\text{Cu}(100)/\text{Pt}(10)/\text{Ta}(3)/\text{Pt}_{0.5}\text{Mn}_{0.5}(15)/\text{Co}_{0.9}\text{Fe}_{0.1}(3)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Fe}_3\text{O}_4(0.6)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Cu}(2.2)/\text{NiFeCo}(2)/\text{Fe}_3\text{O}_4(0.6)/\text{NiFeCo}(1)/\text{Ru}(0.7)/\text{NiFeCo}(2)/\text{Ta}(3)/\text{Pt}(10)$

このようにして作成した磁気抵抗効果素子を Cu/Pt 下部電極を残して $0.3\mu\text{m}$ 角にパターンニングした後、全体を Al_2O_3 膜で絶縁し、上部電極21と、下部電極11とのスルーホールを開け、 Cu より成るセンス線23を別々に上部と下部電極21、22に接続し、更に Al_2O_3 膜で絶縁して、 Cu より成るワード線22を設け、図17に示したような構成のメモリ素子1700とした。実施例15と同様にワード線22に電流を流して $\text{NiFeCo}/\text{Ru}/\text{NiFeCo}$ より成る自由層5

Dを磁化反転して情報を書き込み、次にワード線22に電流を流しセンス線23の抵抗変化を測定してその動作を確認し、メモリ素子1700が構成出来ることがわかった。このように本発明の磁気抵抗素子9を用いたメモリ素子1700は $0.3\mu\text{m}$ 角のセルサイズでも動作することが確認され、かつ実施例15、16で作成したメモリ素子は不揮発性であることが確認された。

【0215】(実施例17) 多元のスパッタカソードを有する成膜装置を用いて、スパッタ法により、図11Bの構成の磁気抵抗効果素子1100Bを作成した。この場合、ターゲットとしては、磁化回転抑制層2用として $\text{Pt}_{0.5}\text{Mn}_{0.5}$ 、下地層7として Ta 、金属磁性層32として $\text{Co}_{0.9}\text{Fe}_{0.1}$ 、非磁性膜33用として Ru 、酸化物磁性膜31、52用として Fe_3O_4 、非磁性層4として Cu 、金属磁性膜51としては $\text{Co}_{0.9}\text{Fe}_{0.1}$ および $\text{Ni}_{0.8}\text{Fe}_{0.2}$ を用いた。スパッタリング用の不活性ガスとしては、 Ar 、 Kr 、 Xe 等があるが、この場合には Ar ガスを用いた。また酸化物磁性膜31、52を作成するときだけ、約1%の O_2 ガスを Ar ガスと一緒に導入した。この酸素ガスを添加する目的は、長期間高真空中でスパッタしたため Fe_3O_4 ターゲットの O 量が比較的低下している場合や高真空中でスパッタリングを行う場合等に成膜された酸化物磁性膜の酸素量を調整するためである。導入する酸素量としては全ガス圧の10%以下程度が適当である。

【0216】上述の長期間高真空中でスパッタしたため Fe_3O_4 ターゲットの O 量が比較的低下している Fe_3O_4 ターゲットを用い、チャンバー内を $1 \times 10^{-9}\text{Torr}$ 以下に排気した後、スパッタリングガスを 0.8mTorr になるまで導入して、 Si 基板上に次の構成の磁気抵抗効果素子を作成した。

【0217】実施例サンプル32 $\text{Ta}(3)/\text{Pt}_{0.5}\text{Mn}_{0.5}(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(1.5)/\text{Fe}_3\text{O}_4(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(1.5)/\text{Cu}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(1)/\text{Ni}_{0.8}\text{Fe}_{0.2}(2)/\text{Fe}_3\text{O}_4(1)/\text{Ta}(3)$

また比較のために酸化物磁性膜の層がない従来例サンプルJを作成した。

【0218】従来例サンプルJ $\text{Ta}(3)/\text{Pt}_{0.5}\text{Mn}_{0.5}(1)/\text{Co}_{0.9}\text{Fe}_{0.1}(2)/\text{Ru}(0.7)/\text{Co}_{0.9}\text{Fe}_{0.1}(3)/\text{Cu}(2)/\text{Co}_{0.9}\text{Fe}_{0.1}(1)/\text{Ni}_{0.8}\text{Fe}_{0.2}(2)/\text{Ta}(3)$

このようにして作成した磁気抵抗効果素子の特性を実施例12と同様の方法で比較した。その結果を表14に示す。

【0219】

【表14】

試料	MR比(%)	Hp(kA/m)
実施例サンプル 32	13.1	80
従来例サンプル J	7.5	80

【0220】表14の結果から分かるように、本発明の実施例サンプル32は酸化物磁性膜31、52の効果でHpの大きさは従来例と変わらないのに、大きなMR比を示していることが分かる。

【0221】また、実施例サンプル32で、酸化物磁性膜52の代わりに Al_2O_3 ターゲットを用いて酸化物非磁性膜である Al_2O_3 膜を形成した実施例サンプル33も作成した。

実施例サンプル33 Ta(3)/Pt_{0.5}Mn_{0.5}(1)/Co_{0.9}Fe_{0.1}(2)/Ru(0.7)/Co_{0.9}Fe_{0.1}(1.5)/Fe₃O₄(1)/Co_{0.9}Fe_{0.1}(1.5)/Cu(2)/Co_{0.9}Fe_{0.1}(1)/Ni_{0.8}Fe_{0.2}(2)/ Al_2O_3 (1)/Ta(3)

この場合、MR比は12.8%と実施例サンプル32と同等であったが、自由層5Aの軟磁気特性が劣化し、実施例サンプル32の自由層5Aの反転磁界(保磁力)が約30eであるのに対して、実施例サンプル33では100eに増大した。これは、酸化物磁性膜52に、単に電子の鏡面反射効果だけでなく、軟性磁気特性を改善する効果もあるためと考えられる。

【0222】

【発明の効果】本発明の磁気抵抗効果素子は従来のものに比べて大きなMR比を実現し、これを用いることにより高出力の磁気抵抗効果型ヘッドを可能とし、更にはこのヘッドを用いて超高密度の磁気記録装置を可能するものである。又本発明の磁気抵抗効果素子を用いれば不揮発性で高密度の磁気抵抗効果メモリー素子が作成出来る。

【図面の簡単な説明】

- 【図1】本発明の磁気抵抗効果素子の断面の模式図。
- 【図2】本発明の磁気抵抗効果素子の断面の模式図。
- 【図3】本発明の磁気抵抗効果素子の断面の模式図。
- 【図4】本発明の磁気抵抗効果素子の断面の模式図。
- 【図5A】本発明の磁気抵抗効果素子の断面の模式図。
- 【図5B】本発明の磁気抵抗効果素子の断面の模式図。
- 【図6】本発明の磁気抵抗効果素子の断面の模式図。
- 【図7】本発明の磁気抵抗効果素子の断面の模式図。
- 【図8】本発明の磁気抵抗効果素子の断面の模式図。
- 【図9】本発明の磁気抵抗効果素子の断面の模式図。

【図10】本発明の磁気抵抗効果素子の断面の模式図。

【図11A】本発明の磁気抵抗効果素子の断面の模式図。

【図11B】本発明の磁気抵抗効果素子の断面の模式図。

【図12】本発明の磁気抵抗効果素子の断面の模式図。

【図13】本発明の磁気抵抗効果素子の断面の模式図。

【図14A】本発明の磁気抵抗効果型ヘッドの一例を示す図。

【図14B】本発明の磁気抵抗効果型ヘッドの一例を示す図。

【図15】本発明のヨーク型磁気抵抗効果型ヘッドの一例を示す図。

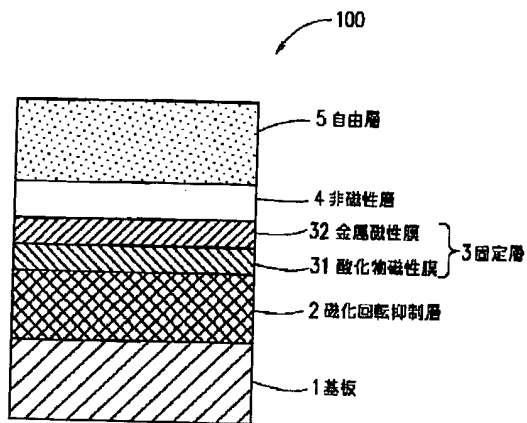
【図16】本発明の磁気記録装置の説明図。

【図17】本発明の磁気抵抗効果メモリー素子の一例を示す図。

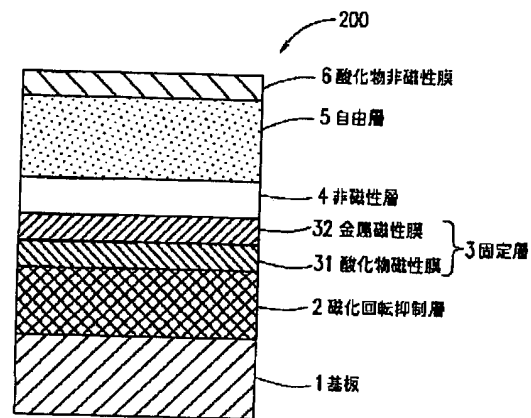
【符号の説明】

- 1 基板
- 2 磁化回転抑制層(ピンニング層)
- 3 磁性膜(固定層)
- 31 酸化物磁性膜
- 32 金属磁性膜
- 33 非磁性膜
- 4 非磁性層
- 5 磁性層(自由層)
- 51 金属磁性膜
- 52 酸化物磁性膜
- 6 酸化物非磁性膜
- 7 下地膜
- 9 MR素子部
- 10 下部シールド
- 11 下部シールドギャップ
- 12 ハードバイアス部
- 13 リード部
- 14 上部シールドギャップ
- 15 上部シールド
- 16 ヨーク部
- 17 絶縁膜
- 18 記録ポール部
- 19 巻き線部
- 20 記録兼再生ギャップ部
- 21 電極部
- 22 情報記録用導体線(ワード線)
- 23 情報読出用導体線(センス線)

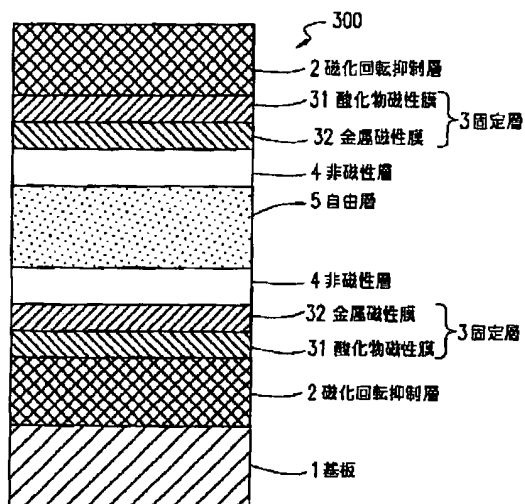
【圖1】



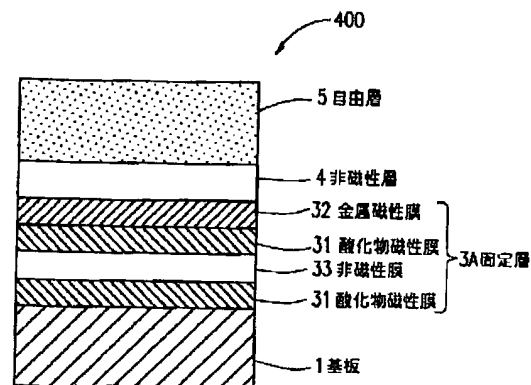
【圖2】



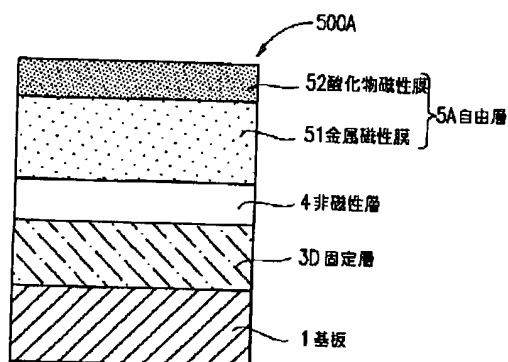
【圖3】



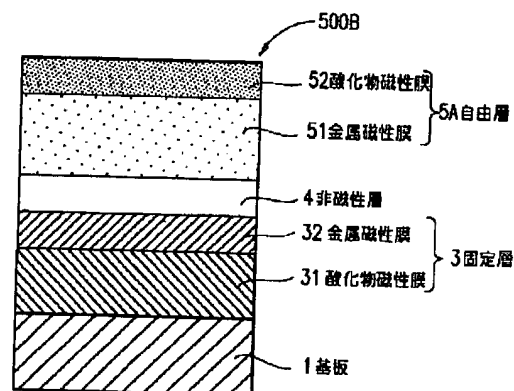
【圖4】



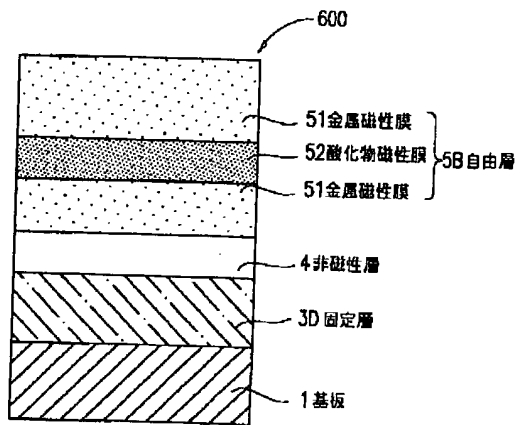
【圖5A】



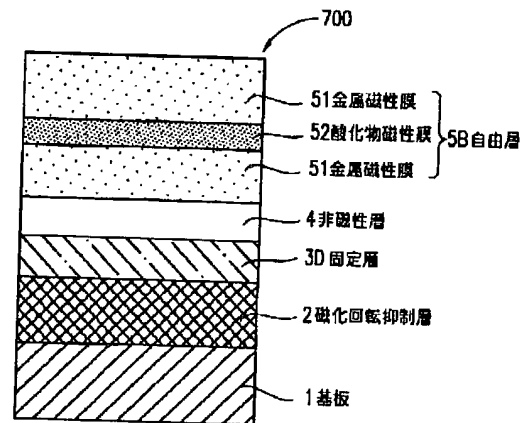
【圖5B】



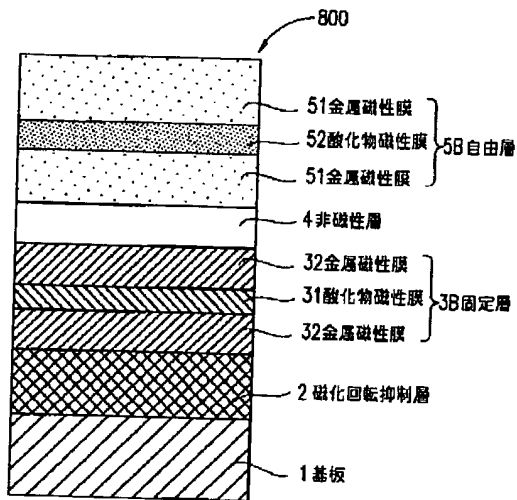
【图6】



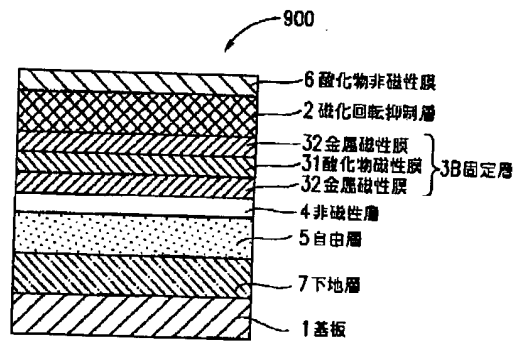
【图7】



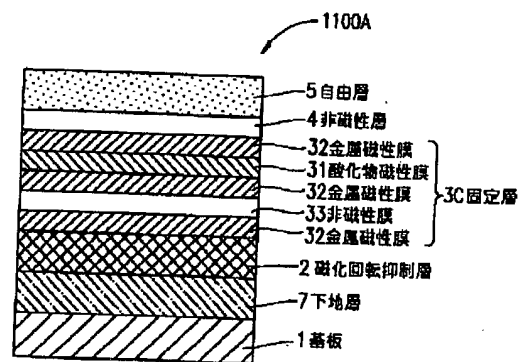
【图8】



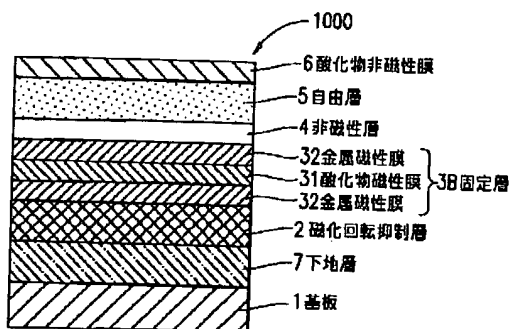
【图9】



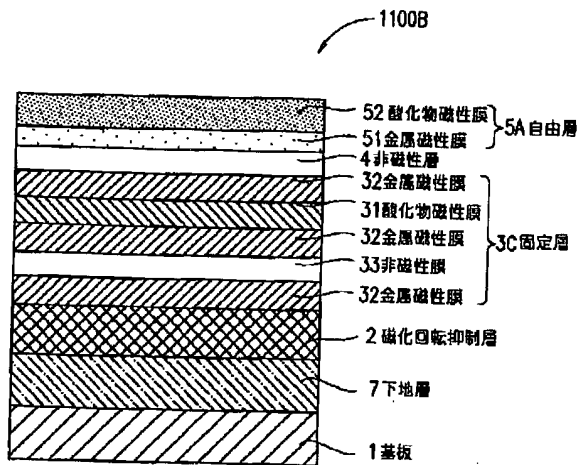
【图11A】



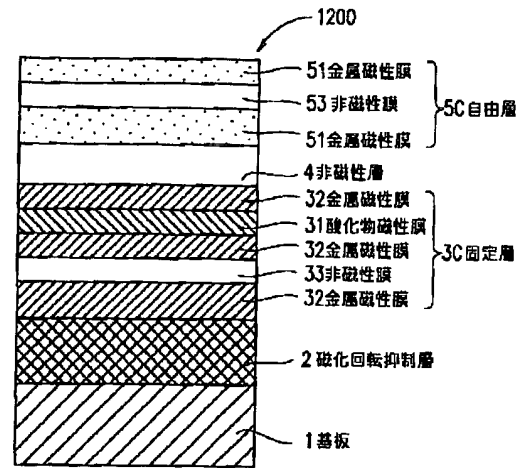
【图10】



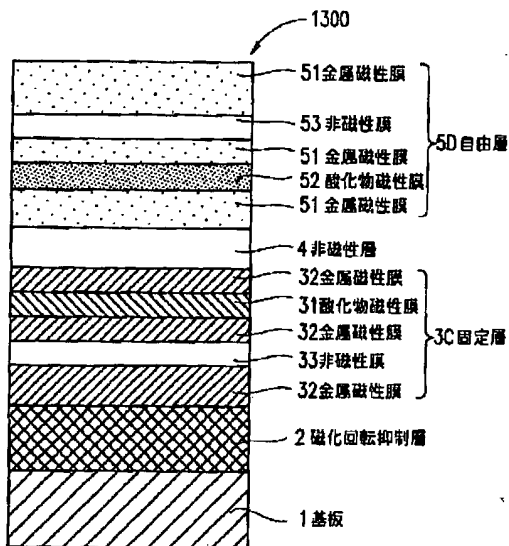
【図11B】



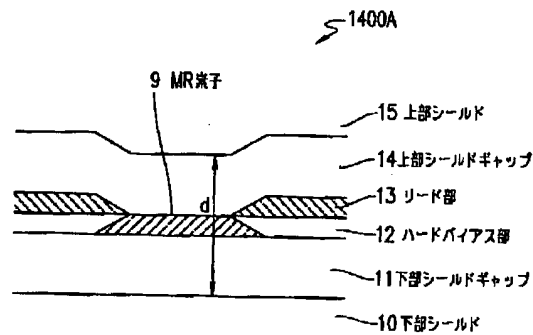
【図12】



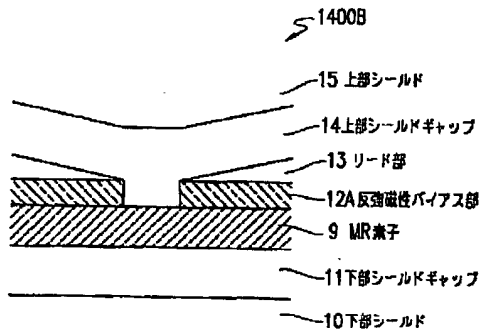
【図13】



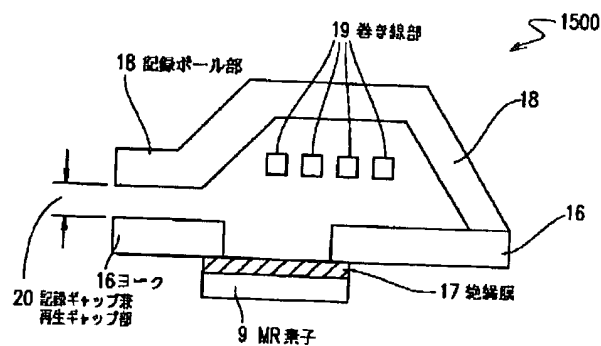
【図14A】



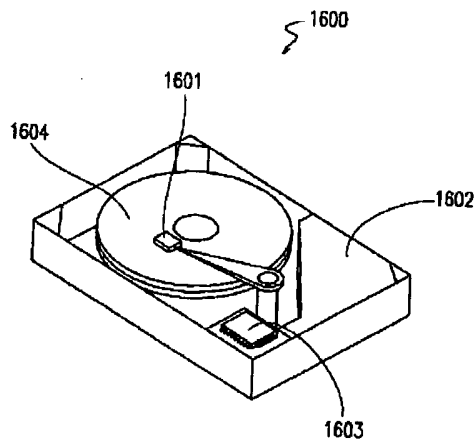
【図14B】



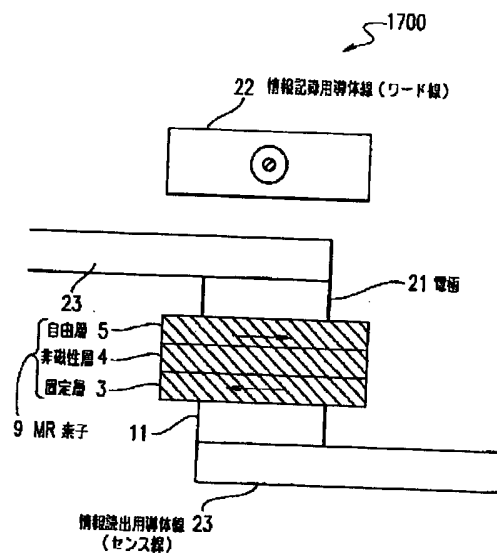
【図15】



【図16】



【図17】



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 (72)発明者 里見 三男
 大阪府門真市大字門真1006番地 松下電器
 産業株式会社内

(72)発明者 川分 康博
 大阪府門真市大字門真1006番地 松下電器
 産業株式会社内
 (72)発明者 平本 雅祥
 大阪府門真市大字門真1006番地 松下電器
 産業株式会社内
 (72)発明者 松川 望
 大阪府門真市大字門真1006番地 松下電器
 産業株式会社内

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(71)Applicant : MATSUSHITA ELECTRIC IND CO LTD

(72)Inventor : SAKAKIMA HIROSHI
SUGITA YASUNARI
SATOMI MITSUO
KAWAWAKE YASUHIRO
HIRAMOTO MASAYOSHI
MATSUKAWA NOZOMI

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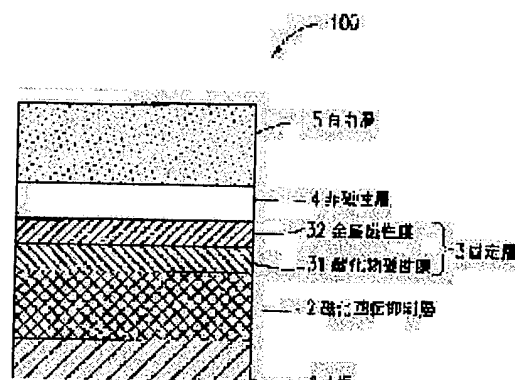
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(54) MAGNETORESISTANCE EFFECT ELEMENT AND ITS MANUFACTURING METHOD, MAGNETORESISTANCE EFFECT TYPE HEAD, MAGNETIC RECORDING DEVICE, AND MAGNETORESISTANCE EFFECT MEMORY ELEMENT

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a magnetoresistance effect element having thermal stability and high MR ratio.

SOLUTION: The magnetoresistance effect element contains a free layer that is easily magnetized and rotated by an external magnetic field, a first nonmagnetic layer, a first fixed layer that is provided at the opposite side of the free layer for the first nonmagnetic layer and will not easily undergo magnetization rotation due to the external magnetic field. At least one of the first fixed layer or the free layer contains a first metal magnetic film that comes into contact with the first nonmagnetic layer and a first oxide magnetic film.



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CLAIMS

[Claim(s)]

- [Claim 1] At least one side of this 1st fixed bed and this free layer is a magneto-resistive effect element containing the 1st metal magnetic film which touches this 1st non-magnetic layer, and the 1st oxide magnetic film including a free layer which carries out a magnetization revolution easily by external magnetic field, the 1st non-magnetic layer, and the 1st fixed bed which is prepared in an opposite hand of this free layer to this 1st non-magnetic layer, and does not carry out a magnetization revolution easily by this external magnetic field.
- [Claim 2] Said 1st fixed bed is a magneto-resistive effect element containing said 1st metal magnetic film and said 1st oxide magnetic film according to claim 1.
- [Claim 3] It is the magneto-resistive effect element according to claim 1 which contains further the 2nd non-magnetic layer prepared in an opposite hand of said 1st non-magnetic layer to said free layer, and the 2nd fixed bed which is prepared in an opposite hand of this free layer to this 2nd non-magnetic layer, and does not carry out a magnetization revolution easily by this external magnetic field.
- [Claim 4] Said free layer is a magneto-resistive effect element containing said 1st metal magnetic film and said 1st oxide magnetic film according to claim 1.
- [Claim 5] A magneto-resistive effect element according to claim 2 which is prepared in an opposite hand of said 1st non-magnetic layer to said free layer, and contains a good oxide nonmagnetic membrane of surface smoothness further.
- [Claim 6] A magneto-resistive effect element according to claim 1 which contains further a magnetization revolution control layer combined with said 1st oxide magnetic film and magnetic target.
- [Claim 7] Said free layer is a magneto-resistive effect element according to claim 4 which contains further the 2nd metal magnetic film prepared in an opposite hand of said 1st metal magnetic film to said oxide magnetic film.
- [Claim 8] A magneto-resistive effect element according to claim 1 which contains a magnetization revolution control layer further although it combines with said 1st fixed bed and magnetic target.
- [Claim 9] Said 1st fixed bed is a magneto-resistive effect element according to claim 1 which contains further the 2nd metal magnetic film prepared in an opposite hand of said 1st metal magnetic film to said 1st oxide magnetic film.
- [Claim 10] Said 1st fixed bed is a magneto-resistive effect element according to claim 1 which contains further a nonmagnetic membrane for switched connection which carries out switched connection of the 2nd metal magnetic film prepared in an opposite hand of said 1st metal magnetic film to said 1st oxide magnetic film, the 3rd metal magnetic film, and this 2nd metal magnetic film and this 3rd metal magnetic film in antiferromagnetism.
- [Claim 11] Said 1st fixed bed is a magneto-resistive effect element according to claim 1 which contains further a nonmagnetic membrane prepared in an opposite hand of said 1st metal magnetic film to said 1st oxide magnetic film, and the 2nd oxide magnetic film which carries out switched connection to this 1st oxide magnetic film and a magnetic target through this nonmagnetic membrane.
- [Claim 12] Said 1st oxide magnetic film is a magneto-resistive effect element containing Fe element according to claim 1.
- [Claim 13] Said 1st oxide magnetic film is a magneto-resistive effect element containing Fe element and X element according to claim 1. However, X is one sort or two sorts or more of elements chosen from a group which consists of aluminum, Si, B, and N.
- [Claim 14] Said 1st oxide magnetic film is a magneto-resistive effect element according to claim 1 which uses as a principal component MFe_2O_4 (one sort or two sorts or more of elements with which M is chosen from Fe, Co, and nickel).
- [Claim 15] Said 1st oxide magnetic film is a magneto-resistive effect element according to claim 1 which uses Fe_3O_4 as a principal component.
- [Claim 16] Said 1st oxide magnetic film is a magneto-resistive effect element according to claim 1 which uses CoFe
- http://www4.ipdl.jpo.go.jp/cgi-bin/tran_web.cgi_ejje?u=http%3A%2F%2Fwww4.ipdl.jpo.go.jp%2FTokuj... 1/30/2004

2O₄ as a principal component.

[Claim 17] Said magnetization revolution control layer is a magneto-resistive effect element according to claim 6 which consists of a P-Mn system (one-sort or two sorts or more of elements with which P is chosen from Pt, nickel, Pd, Ir, Rh, Ru, and Cr) alloy.

[Claim 18] Said magnetization revolution control layer is a magneto-resistive effect element according to claim 6 which consists of alpha-Fe₂O₃, either of the NiO(s), or these cascade screens.

[Claim 19] Said this magnetization revolution control layer is a magneto-resistive effect element according to claim 6 characterized by consisting of a (AB)₂OX layer. However, in (AB)₂OX, it is shown that a ratio of A, a thing which added B element, and O element is 2:X, and O satisfies conditions of an oxygen atom $2.8 < X < 3.2$, and they are atoms A, B, and O. It is an ionic radius as R_a, R_b, and R_o, respectively Degree type $t = (R_a + R_o) / (\sqrt{2} - (R_b + R_o))$. It satisfies that t come out of and defined is $0.8 < t < 0.97$.

[Claim 20] A magneto-resistive effect element according to claim 19 which is the transition-metals element with which B of the aforementioned (AB)₂OX layer uses Fe as a principal component.

[Claim 21] A magneto-resistive effect element according to claim 19 which are one sort or two sorts or more of elements with which A of the aforementioned (AB)₂OX layer is chosen from rare earth elements (Y and La are included).

[Claim 22] Said 1st oxide magnetic film is a magneto-resistive effect element according to claim 1 which is the oxide of said 1st metal magnetic film.

[Claim 23] Said 1st metal magnetic film is a magneto-resistive effect element according to claim 22 which consists of a Co-Fe alloy.

[Claim 24] This free layer is a magneto-resistive effect element containing two different metal magnetic films of thickness or saturation magnetization which carried out switched connection in antiferromagnetism especially through a nonmagnetic membrane and said nonmagnetic membrane according to claim 1.

[Claim 25] A magneto-resistive effect element according to claim 1 which passes current at right angles to said film surface, including further an electrode with which a film surface of said magneto-resistive effect element is arranged up and down.

[Claim 26] A magneto-resistive effect mold arm head possessing a magneto-resistive effect element according to claim 1 and the shield section.

[Claim 27] A magneto-resistive effect mold arm head possessing a magneto-resistive effect element according to claim 1 and a yoke which introduces into said magnetic resistance element a magnetic field which should be detected.

[Claim 28] A magnetic recording medium equipped with the servo section which controls tracking of a magneto-resistive effect mold arm head according to claim 26, and a record medium and this magneto-resistive effect mold arm head processes a signal which carries out record playback to this record medium.

[Claim 29] an object for information read-out for reading information from a magneto-resistive effect element according to claim 1 and this magneto-resistive effect element -- a conductor -- a line and an object for the information record for recording this information -- a conductor -- a magneto-resistive effect memory device possessing a line.

[Claim 30] A manufacture method of a magneto-resistive effect element which is the manufacture method of a magneto-resistive effect element according to claim 1, and includes the 1st process which forms said 1st oxide magnetic film by spatter using an oxide target.

[Claim 31] Said oxide target is the manufacture method of a magneto-resistive effect element containing Fe₃O₄ according to claim 30.

[Claim 32] Said 1st process is the manufacture method of a magneto-resistive effect element according to claim 30 which includes the 2nd process which forms said 1st oxide magnetic film by spatter using inert gas and oxygen gas.

[Claim 33] Said 1st process is the manufacture method of a magneto-resistive effect element according to claim 31 which includes the 2nd process which forms said 1st oxide magnetic film by spatter using inert gas and oxygen gas.

[Claim 34] Said oxide target is the manufacture method of a magneto-resistive effect element containing CoFe₂O₄ according to claim 30.

[Claim 35] The 1st process which carries out the laminating of the metal magnetic film of a free layer which carries out a magnetization revolution easily by external magnetic field through a direct or substrate layer on a substrate, a non-magnetic layer, and the fixed bed which does not carry out a magnetization revolution easily by external magnetic field one by one, A manufacture method of a magneto-resistive effect element which includes the 2nd process which oxidizes a front face of this metal magnetic film of this fixed bed, the 3rd process which forms an oxide magnetic film on a front face of this metal magnetic film, and the 4th process which forms a magnetization revolution control layer further on

this oxide magnetic film.

[Claim 36] Said 2nd process is the manufacture method of a magneto-resistive effect element including a plasma oxidation method according to claim 35.

[Claim 37] Said 2nd process is the manufacture method of a magneto-resistive effect element according to claim 35 which includes a process which oxidizes said front face of said metal magnetic film by oxygen radical generated from a source of an oxygen radical.

[Claim 38] Said 2nd process is the manufacture method of a magneto-resistive effect element including a natural oxidation method according to claim 35.

[Claim 39] Said 2nd process is the manufacture method of a magneto-resistive effect element including a process which oxidizes said front face of said metal magnetic film using oxygen ion generated from the ion source according to claim 35.

[Claim 40] The 1st process which carries out the laminating of the 1st metal magnetic film of a free layer which carries out a magnetization revolution easily by external magnetic field through a direct or substrate layer on a substrate, a non-magnetic layer, and the fixed bed which does not carry out a magnetization revolution easily by external magnetic field one by one, The 2nd process which forms an oxide magnetic film of this fixed bed by reactive-sputtering method, A manufacture method of a magneto-resistive effect element which includes the 3rd process which forms the 2nd metal magnetic film of this fixed bed on it [this / oxide magnetic film], and the 4th process which forms a magnetization revolution control layer further on this 2nd metal magnetic film.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] This invention relates to a magnetic recording medium and its manufacture methods, such as a magneto-resistive effect element which produces a big output by magnetic-reluctance change to an external magnetic field, a magneto-resistive effect mold arm head suitable for the high density magnetic-recording playback constituted using it, and HDD using this.

[0002]

[Description of the Prior Art] In recent years, the densification of HDD (hard disk drive) is remarkable, and its advance of the playback magnetic head which reads the magnetization recorded on data medium is also remarkable. The magneto-resistive effect element (MR element) called the spin bulb which used giant magneto-resistance especially is briskly studied as what goes up substantially the sensitivity of the magneto-resistive effect mold arm head (MR head) used now.

[0003] Two ferromagnetic layers are arranged through a non-magnetic layer, and a spin bulb fixes the magnetization direction of one magnetic layer (fixed bed) by the exchange bias magnetic field by the magnetization revolution control layer (pinning layer) (the ferromagnetic layer at this time and a magnetization revolution control layer are doubled, and it is called a switched connection film). By moving comparatively freely the magnetization direction of another magnetic layer (free layer) according to an external magnetic field, whenever [angular relation / of the magnetization direction of the fixed bed and a free layer] is changed, and change of electric resistance is produced.

[0004] As a material used for a spin bulb film, as a magnetic film at the beginning A nickel-Fe film, As a nonmagnetic membrane, Cu, It is the thing using Fe-Mn as a magnetization revolution control layer. About 2% of thing was proposed for magnetic-reluctance rate of change (MR ratio) (journal OBUMAGUNETIZUMU and magnetic MATERIARUZU 93 101st term (1991) ()). [Journal of Magnetism] and Magnetic Materials 93 and p -- 101 and 1991. Thus, the thing using the FeMn film as a magnetization revolution control layer has small MR ratio, and blocking temperature (temperature whose magnetization fixed effect of the fixed bed by the magnetization revolution control layer is lost) is not high enough, and since a difficulty is in corrosion resistance at the FeMn itself, the spin bulb film using a various magnetization revolution control layer is proposed. Especially a PtMn system has corrosion resistance and good thermal stability, and, as for the spin bulb film using the oxide of NiO or alpha-Fe 2O3 grade as a magnetization revolution control layer, the large thing is obtained as by leaps and bounds [MR ratio] as 15% or more.

[0005]

[Problem(s) to be Solved by the Invention] However, in the case of a NiO film, there is a problem in the thermal stability of a NiO spin bulb film sufficiently highly [blocking temperature].

[0006] Moreover, when an alpha-Fe 2O3 spin bulb film also has a defect with the weak pinning effect of a metal magnetic film and it considers as the spin bulb of dual spin bulb structure or the structure which attached alpha-Fe 2O3 on the fixed bed especially, this inclination is remarkable in 2Oalpha-Fe 3 upside film. Although a PtMn system is excellent in thermal stability, it has the technical problem from which big MR ratio in NiO or about 2O3 alpha-Fe is not obtained. Therefore, coexistence of a big MR ratio like thermal stability like a PtMn system and 2ONiO and alpha-Fe 3 system was one technical problem.

[0007] Furthermore, the total thickness of the metal membrane section which shows a magneto-resistive effect more was thin, and it was a technical problem to obtain the magneto-resistive effect element which shows bigger MR ratio.

[0008] The object of this invention is to offer the magneto-resistive effect element which has thermal stability and a high MR ratio, and the manufacture method, a magneto-resistive effect mold arm head, a magnetic recording medium and a magneto-resistive effect memory device.

[0009]

[Means for Solving the Problem] In order to solve the above technical problem, in this invention, it is characterized by using a cascade screen of a metal magnetic film and an oxide magnetic film for the fixed bed which gives details below. If it becomes possible to obtain bigger MR ratio by considering as this configuration, for example, a PtMn system etc. is used for a magnetization revolution control layer with this configuration, it will become compatible [thermal stability and a high MR ratio].

[0010] A free layer in which a magneto-resistive effect element concerning this invention carries out a magnetization revolution easily by external magnetic field, It is prepared in an opposite hand of this free layer to the 1st non-magnetic layer and this 1st non-magnetic layer. The above-mentioned object is attained by that including the 1st metal magnetic film with which at least one side of this 1st fixed bed and this free layer touches this 1st non-magnetic layer, and the 1st oxide magnetic film including the 1st fixed bed which does not carry out a magnetization revolution easily by this external magnetic field.

[0011] Said 1st fixed bed may also contain said 1st metal magnetic film and said 1st oxide magnetic film.

[0012] The 2nd non-magnetic layer prepared in an opposite hand of said 1st non-magnetic layer to said free layer and the 2nd fixed bed which is prepared in an opposite hand of this free layer to this 2nd non-magnetic layer, and does not carry out a magnetization revolution easily by this external magnetic field may also be included further.

[0013] Said free layer may also contain said 1st metal magnetic film and said 1st oxide magnetic film.

[0014] It is prepared in an opposite hand of said 1st non-magnetic layer to said free layer, and a good oxide nonmagnetic membrane of surface smoothness may also be included further.

[0015] A magnetization revolution control layer combined with said 1st oxide magnetic film and magnetic target may also be included further.

[0016] Said free layer may also contain further the 2nd metal magnetic film prepared in an opposite hand of said 1st metal magnetic film to said oxide magnetic film.

[0017] Although it combines with said 1st fixed bed and magnetic target, a magnetization revolution control layer may also be included further.

[0018] Said 1st fixed bed may also contain further the 2nd metal magnetic film prepared in an opposite hand of said 1st metal magnetic film to said 1st oxide magnetic film.

[0019] Said 1st fixed bed may also contain further a nonmagnetic membrane for switched connection which carries out switched connection of the 2nd metal magnetic film prepared in an opposite hand of said 1st metal magnetic film to said 1st oxide magnetic film, the 3rd metal magnetic film, and this 2nd metal magnetic film and this 3rd metal magnetic film in antiferromagnetism.

[0020] Said 1st fixed bed may also contain further a nonmagnetic membrane prepared in an opposite hand of said 1st metal magnetic film to said 1st oxide magnetic film, and the 2nd oxide magnetic film which carries out switched connection to this 1st oxide magnetic film and a magnetic target through this nonmagnetic membrane.

[0021] Said 1st oxide magnetic film may contain Fe element.

[0022] Said 1st oxide magnetic film may contain Fe element and X element. However, X is one sort or two sorts or more of elements chosen from a group which consists of aluminum, Si, B, and N.

[0023] Said 1st oxide magnetic film is good also considering MFe_2O_4 (one sort or two sorts or more of elements with which M is chosen from Fe, Co, and nickel) as a principal component.

[0024] Said 1st oxide magnetic film is good also considering Fe_3O_4 as a principal component.

[0025] Said 1st oxide magnetic film is good also considering CoFe_2O_4 as a principal component.

[0026] Said magnetization revolution control layer may consist of a P-Mn system (one-sort or two sorts or more of elements with which P is chosen from Pt, nickel, Pd, Ir, Rh, Ru, and Cr) alloy.

[0027] Said magnetization revolution control layer may consist of $\alpha\text{-Fe}_2\text{O}_3$, either of the NiO(s) , or these cascade screens.

[0028] Said this magnetization revolution control layer is a magneto-resistive effect element according to claim 6 characterized by consisting of a $(\text{AB})_2\text{OX}$ layer. However, it is shown that a ratio of A, a thing which added B element, and O element is $2:X$ in $(\text{AB})_2\text{OX}$. O satisfies conditions of the oxygen atom $2.8 < X < 3.2$, and is Atoms A, B, and O. It satisfies that t defined by degree type $t = (\text{Ra} + \text{Ro}) / (\sqrt{2} - (\text{Rb} + \text{Ro}))$ as Ra, Rb, and Ro in an ionic radius, respectively is $0.8 < t < 0.97$.

[0029] B of the aforementioned $(\text{AB})_2\text{OX}$ layer may be the transition-metals element which uses Fe as a principal component.

[0030] A of the aforementioned $(\text{AB})_2\text{OX}$ layer may be one sort or two sorts or more of elements chosen from rare earth elements (Y and La are included).

[0031] Said 1st oxide magnetic film may be the oxide of said 1st metal magnetic film.

[0032] Said 1st metal magnetic film may consist of a Co-Fe alloy.

[0033] This free layer may also contain especially a nonmagnetic membrane and two metal magnetic films with which thickness or saturation magnetization which carried out switched connection in antiferromagnetism through said nonmagnetic membrane is different.

[0034] Current may be passed at right angles to said film surface, including further an electrode with which a film surface of said magneto-resistive effect element is arranged up and down.

[0035] A magneto-resistive effect mold arm head concerning this invention possesses a magneto-resistive effect element concerning this invention, and the shield section, and the above-mentioned object is attained by that.

[0036] Other magneto-resistive effect mold arm heads concerning this invention are the magneto-resistive effect elements concerning this invention. A yoke which introduces into said magnetic resistance element a magnetic field which should be detected is provided, and the above-mentioned object is attained by that.

[0037] A magnetic recording medium concerning this invention is equipped with the servo section which controls tracking of a magneto-resistive effect mold arm head concerning this invention, and a record medium and this magneto-resistive effect mold arm head, and the signal-processing section to which this magneto-resistive effect mold arm head processes a signal which carries out record playback to this record medium, and the above-mentioned object is attained by that.

[0038] an object for information read-out for a magneto-resistive effect memory device concerning this invention to read information from a magneto-resistive effect element concerning this invention, and this magneto-resistive effect element -- a conductor -- a line and an object for the information record for recording this information -- a conductor -- a line is provided and the above-mentioned object is attained by that.

[0039] A manufacture method of a magneto-resistive effect element concerning this invention is the manufacture method of a magneto-resistive effect element concerning this invention, the 1st process which forms said 1st oxide magnetic film by spatter using an oxide target is included, and the above-mentioned object is attained by that.

[0040] Said oxide target may also contain Fe 3O4.

[0041] Said 1st process may include the 2nd process which forms said 1st oxide magnetic film by spatter using inert gas and oxygen gas.

[0042] Said 1st process may include the 2nd process which forms said 1st oxide magnetic film by spatter using inert gas and oxygen gas.

[0043] Said oxide target may also contain CoFe 2O4.

[0044] A manufacture method of other magneto-resistive effect elements concerning this invention The 1st process which carries out the laminating of the metal magnetic film of a free layer which carries out a magnetization revolution easily by external magnetic field through a direct or substrate layer on a substrate, a non-magnetic layer, and the fixed bed which does not carry out a magnetization revolution easily by external magnetic field one by one, The 2nd process which oxidizes a front face of this metal magnetic film of this fixed bed, the 3rd process which forms an oxide magnetic film on a front face of this metal magnetic film, and the 4th process which forms a magnetization revolution control layer further on this oxide magnetic film are included, and the above-mentioned object is attained by that.

[0045] Said 2nd process may also include a plasma oxidation method.

[0046] Said 2nd process may also include a process which oxidizes said front face of said metal magnetic film by oxygen radical generated from a source of an oxygen radical.

[0047] Said 2nd process may also include a natural oxidation method.

[0048] Said 2nd process may also include a process which oxidizes said front face of said metal magnetic film using oxygen ion generated from the ion source.

[0049] A manufacture method of other magneto-resistive effect elements to a pan concerning this invention The 1st process which carries out the laminating of the 1st metal magnetic film of a free layer which carries out a magnetization revolution easily by external magnetic field through a direct or substrate layer on a substrate, a non-magnetic layer, and the fixed bed which does not carry out a magnetization revolution easily by external magnetic field one by one, The 2nd process which forms an oxide magnetic film of this fixed bed by reactive-sputtering method, The 3rd process which forms the 2nd metal magnetic film of this fixed bed on it [this / oxide magnetic film], and the 4th process which forms a magnetization revolution control layer further on this 2nd metal magnetic film are included, and the above-mentioned object is attained by that.

[0050]

[Embodiment of the Invention] for constituting the spin bulb film of this invention, it was shown at drawing 1 -- as -- [metal magnetic film 32 / oxide a magnetic film (free layer 5) / non-magnetic layer 4 / magnetic film 31] (fixed bed 3) /

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magnetization revolution control layer 2 (pinning layer) -- it considers as a configuration and considers as the configuration which the metal magnetic film 32 of a non-magnetic layer 4 and the fixed bed 3 meets with, and the oxide magnetic film 31 of the magnetization revolution control layer 2 and the fixed bed 3 meets with.

[0051] Moreover, the oxide nonmagnetic membrane 6 may be attached to the field of the free layer 5 which does not touch the above-mentioned non-magnetic layer 4 as shown in drawing 2. At this time, a flat thing is important for the interface of the free layer 5 and the oxide non-magnetic layer 6.

[0052] furthermore, it was shown in drawing 3 -- as -- [oxide magnetic film 31 / metal magnetization revolution control layer 2 (pinning layer) / magnetic film 32] (fixed bed 3) / non-magnetic layer 4 -- [metal magnetic film 32 / oxide a / magnetic film (free layer 5) / non-magnetic layer 4 / magnetic film 31] (fixed bed 3) / magnetization revolution control layer 2 (pinning layer) -- it is good also as a configuration.

[0053] Moreover, as shown in drawing 5 A, free layer 5A may constitute this invention from a cascade screen of the metal magnetic film 51 which touches this non-magnetic layer 4, and the oxide magnetic film 52. What carried out the laminating of a metal magnetic film and the oxide magnetic film may be used for fixed-bed 3D of drawing 5 A.

[0054] As free layer 5B showed especially drawing 6, you may consist of [metal magnetic film 51 / oxide magnetic film 52 / a metal magnetic film 51].

[0055] Although shown in these drawing 5 A and 6, the fixed bed is good also as a configuration which touches the magnetization revolution control layer 2 as shown in drawing 7. Furthermore, as it is good also as the same configuration as drawing 1, 2, or drawing 4 mentioned later and the fixed-bed 3D was shown in drawing 8, the fixed bed may consist of [metal magnetic film 32 / oxide magnetic film 31 / a metal magnetic film 32].

[0056] In addition, it is good also considering drawing 7 and the free layer of 8 as a configuration like drawing 5 A. [0057] What contains Fe element as these oxides magnetic film is desirable. For example, the thing of the Fe-X (X is 4 - 30% at atomic %) system containing Fe element and X element combines soft magnetic characteristics and high resistance. However, X is one sort or two sorts or more of elements chosen from the group which consists of aluminum, Si, B, and N. It is FeAlO by reactive sputtering as a forming-membranes method, use Fe-aluminum, Fe-Si, Fe-B, etc. for a target, and using oxygen and nitrogen. FeSiO, FeBO, FeAlON, FeSiON, FeBON, FeAlSiO, FeAlSiON, etc. can be formed. Although resistance is lower than 2OMFe4 system described below, there are membrane formation conditions and an advantage which can adjust resistance by presentation.

[0058] Moreover, as for the above-mentioned oxide magnetic film, it is desirable to constitute MFe 2O4 (one sort or two sorts or more of elements with which M is chosen from Fe, Co, and nickel) as a principal component.

[0059] In order to become high resistance from the above-mentioned Fe-X system further if Fe 3O4 is constituted as a principal component in the oxide magnetic film in this case, to become high resistance further if what uses CoFe 2O4 as a principal component is used, and to show hard magnetic properties in this case, it is suitable for using it as a part of fixed bed.

[0060] the above-mentioned pinning layer consists of a P-Mn system (one-sort or two sorts or more of elements with which P is chosen from Pt, nickel, Pd, Ir, Rh, Ru, and Cr) alloy -- ** -- although it is desirable -- alpha-Fe 2 -- you may consist of O3, NiO, or these cascade screens, and may consist of (AB)2OX films. However, in (AB)2OX, it is shown that the ratio of A, the thing which added B element, and O element is 2:X, and O is satisfied with an oxygen atom of the conditions of $2.8 < X < 3.2$, and they are Atoms A, B, and O. It is an ionic radius as Ra, Rb, and Ro, respectively Degree type $t = (Ra + Ro) / (\sqrt{2} - (Rb + Ro))$

It satisfies that t come out of and defined is $0.8 < t < 0.97$.

[0061] In this case, as for B of a (AB)2OX layer, it is desirable that it is the transition-metals element which uses Fe as a principal component, and, as for A, it is desirable that they are one sort or two sorts or more of elements chosen from rare earth elements (Y and La are included).

[0062] the case where a pinning layer comes downward as shown in drawing 1 although these films are formed on a substrate of a spatter etc. -- as a pinning layer -- alpha-Fe 2 -- it is desirable to use O3, NiO, and a (AB)2OX film, and when a pinning layer comes by the configuration of vertical reverse upwards, the P-Mn system of drawing 1 is desirable. however, a Pt-Mn system -- the upper and lower sides -- it can respond to both.

[0063] The same is said of drawing 2 and an independently desirable thing may be used for an up-and-down pinning layer in drawing 3.

[0064] When special, as shown [*****] in drawing 4, this fixed-bed 3A may consist of cascade screens of the metal magnetic film 32 which touches this non-magnetic layer 4, and the oxide magnetic film 31 which is carrying out switched connection magnetically through the nonmagnetic membrane 33.

[0065] Furthermore, it is good also as a configuration like drawing 9 -13 which combined suitably drawing 1 -2 described above, drawing 4, and drawing 5 A and drawing 8.

[0066] Although drawing 9 makes reverse the upper and lower sides of the configuration of drawing 8 and the free layer 5 is used as a monolayer like the configuration of drawing 1 -3, in order to raise the soft magnetic characteristics of the free layer 5, the substrate layer 7 is formed.

[0067] Drawing 10 is the thing of a configuration of having used monolayer for the free layer 5 on the basis of the configuration of drawing 8, and having formed the oxide nonmagnetic membrane 6 in the upper part. Moreover, in order to raise the property of the magnetization revolution control layer 2, the substrate layer 7 is formed.

[0068] Drawing 11 A carries out switched connection of the one metal magnetic film 32 which touches the magnetization revolution control layer 2 on the basis of the configuration of drawing 10 and which will be rich metal magnetic film 32 magnetically like fixed-bed 3A of drawing 4 through a nonmagnetic membrane 33. Usually, the effect which heightens the pinning effect of the magnetization revolution control layer 2 by this is acquired using an antiferromagnetism-[this switched connection] thing. In this case, unlike drawing 4, the metal magnetic film 32 is used. In addition, unlike drawing 10, there is no oxide nonmagnetic membrane on the free layer 5 in this case, but an oxide film may be prepared in the upper part as a cap, and a metaled protective coat may be prepared.

[0069] Although current is usually passed in a film surface with the magneto-resistive effect element described above, since it has an oxide magnetic layer, it is possible to consider as the configuration which the film surface of an element arranges especially an electrode up and down, and passes current at right angles to a film surface.

[0070] The magneto-resistive effect mold arm heads of this invention are two kinds of things characterized by coming to provide what possesses shields 10 and 15 for the magneto-resistive effect element 9 of this invention further, and becomes it as shown in drawing 14 A, 14B, and drawing 15, and the yoke 16 which is prepared that the magnetic field which should be detected should be introduced into the magneto-resistive effect element 9, and is constituted using a soft magnetic material in **. Drawing 14 A has the hard bias section 12, and drawing 14 B has the composition of having antiferromagnetism bias section 12A.

[0071] Although the inside of a film surface was considered as the configuration in which current flows by a diagram, if the lead section 13 of drawing 14 A and 14B is attached to the film surface upper and lower sides of the MR element 9 and it ties with the up shield 15 and the lower shield 10, it will become the configuration that current flows to a film surface perpendicular, and will become advantageous structure to narrow-gap-izing (however, it is necessary to insulate the hard bias section 12 and an element 9 in this case or, and the hard

Drawing 16 is the block diagram of the magnetic recording medium 1600 produced using the magnetic head described above. The magnetic recording medium is realized from the disk 1604 which records information, record and the magnetic-head section 1601 to reproduce, the signal-processing section 1603, and the servo section 1602 that considers the tracking of a disk as an arm head. In this magnetic recording medium using the magnetic head of this invention, high density record is more possible than before.

[0072] If the sense line 23 for reading information to the magneto-resistive effect element stated above further and the word line 22 for recording information are provided, it will become the magneto-resistive effect memory device 1700 as shown in drawing 17, and if these elements are arranged in the shape of a matrix, the so-called MRAM (magnetic-reluctance random access memory) is constituted.

[0073] The magneto-resistive effect element of this invention, a magneto-resistive effect mold arm head, and a magnetic-reluctance memory device are explained to details based on a drawing below.

[0074] An example of the cross section showing the configuration of the magneto-resistive effect element 100 of this invention in drawing 1 is shown. In drawing 1, the laminating of the magnetization revolution control layer 2, the fixed bed 3 (oxide magnetic film 31 / metal magnetic film 32), a non-magnetic layer 4, and the free layer 5 is carried out one by one on the substrate 1. Pinning of the magnetization of the oxide magnetic film 31 of the fixed bed 3 is carried out by the exchange bias magnetic field by the magnetization revolution control layer 2, and since it has joined together in ferromagnetism, pinning of the oxide magnetic film 33 and the metal magnetic film 32 is carried out in the direction as magnetization of the oxide magnetic film 33 where magnetization of the metal magnetic film 32 is also the same. Since it is separated more magnetically than the fixed bed 3 by the non-magnetic layer 4, the free layer 5 which is one magnetic substance can be moved comparatively freely by the magnetic field from the outside. When the magnetization directions of two magnetic layers are generally anti-parallel, electrons are scattered about by the magnetic layer / [non-magnetic layer] interface, and resistance of an element becomes high.

[0075] On the other hand, when the magnetization direction is the same, resistance of an element becomes low that there is little dispersion of the electron in an interface. Therefore, the angle of magnetization of the fixed bed 3 and the free layer 5 changes relatively, and the electric resistance of an element changes with them. Resistance change which attached the electrode to the free layer 5 of drawing 1, and produced current by the sink and the magnetic field from the outside as a magnetic-reluctance sensor can be read as an electrical signal. moreover, the structure on the substrate 1 of

drawing 1 (the magnetization revolution control layer 2 - free layer 5) -- the upper and lower sides -- it is good even if reverse. In this case, an electrode needs to remove the upside magnetization revolution control layer 2 and the upside oxide magnetic film 33, and needs to touch the metal magnetic film 32. In addition, although the magnetization revolution control layer 2 was shown in drawing 1, if fixed-bed 3 the very thing is the big hard magnetic film of the coercive force which does not carry out a magnetization revolution easily, the magnetization revolution control layer 2 is unnecessary.

[0076] In addition, in drawing 1, the magnetization revolution control layer 2 is not necessarily required. For example, if the oxide magnetic film 31 is a big hard magnetic film of coercive force, this and the metal magnetic film 32 join together magnetically, even when he has no magnetization revolution control layer 2, a role of the fixed bed is played enough, and a magneto-resistive effect element can be constituted.

[0077] As this invention persons were shown in drawing 1 paying attention to R and ΔR decreasing according to a shunt effect if the factor which governs magnetic reluctance is mostly decided by the magnetic layer / [non-magnetic layer] interface, and the thickness increases when a magnetic layer is a metal membrane, the interface of a non-magnetic layer 4 and the fixed bed 3 was made into a metal/metal interface, and the portion of the remaining fixed bed has improved the reduction of R and ΔR by the shunt effect as an oxide magnetic film. Resistance R of the whole element can be made high by this, and since the output of an element is proportional to resistance variation ΔR and product: $I \Delta R$ of element current I, improvement in the output of it is attained. On the other hand, when there is no oxide magnetic film 31 by a diagram, the resistance R of a spin bulb film becomes small, and when the magnetization revolution control layer 2 is a metal membrane, even if reduction of this R is remarkable and MR ratio (rate of magnetic-reluctance-izing): $\Delta R/R$ is able to take out the same value especially, an output decreases. In addition, as for the interface of the oxide magnetic film 31 and the metal magnetic film 32, it is desirable for irregularity to have surface smoothness 0.5nm or less. It is because resistance will become high and MR ratio will fall, even when magnetization of a magnetic layer is parallel if surface smoothness is bad.

[0078] Generally, when the magnetic film (fixed bed) with which pinning of the magnetization revolution control layer is carried out although MR ratio with the bigger direction in the case of an oxide film than a metal membrane is obtained is a metal membrane, there is a defect with the weak pinning effect. This technical problem improves by using as an oxide magnetic film the fixed bed which touches a magnetization revolution control layer as mentioned above.

[0079] Drawing 2 is the magneto-resistive effect element 200 which is going to form the oxide nonmagnetic membrane 6 excellent in surface smoothness in the front face of the free layer 5 further, tends to be made to carry out specular reflection of the electron in a front face, is going to make lower resistance when magnetization of a magnetic layer is parallel by this, and is going to obtain big MR ratio. In this case, reflection effect with it is not acquired, either. [desirable / as for the interface of the oxide nonmagnetic membrane 6 and the free layer 5 / otherwise, for irregularity to have surface smoothness 0.5nm or less and] [sufficient]

[0080] In addition, as long as it does not degrade the soft magnetic characteristics of the free layer 5, the good oxide magnetic film of surface smoothness is sufficient as the above-mentioned oxide film. Moreover, the metallic reflection film, i.e., Ag, which carries out specular reflection of the electron, and Au film may be prepared in the front face of the free layer 5. In this case, since MR ratio will fall by the shunt effect if a metallic reflection film is too thick, it is good to be desirably referred to [10nm or less] as 3nm or less.

[0081] In this case, as for the interface of a metallic reflection film and the free layer 5, it is desirable for irregularity to have surface smoothness 0.5nm or less, and when that is not right, sufficient reflection effect is not acquired, either. Furthermore, an above-mentioned oxide nonmagnetic membrane may be prepared on this metallic reflection film. Moreover, structure shown in drawing 2 may be made into vertical reverse.

[0082] When it is made vertical reverse, an electrode needs to remove the upside magnetization revolution control layer 2 and the upside oxide magnetic film 31, and needs to touch the metal magnetic film 32.

[0083] Drawing 3 is the magneto-resistive effect element 300 of the dual spin bulb structure where this invention was used, and it is the features that MR ratio big since the magnetic layer / [non-magnetic layer] interface from which an electron receives magnetic dispersion compared with the structure of drawing 1 increase is generally obtained. In order that current may mainly flow the inside across which it faced with two oxide magnetic films 31, there is little reduction in R, and since MR ratio increases, it becomes possible [obtaining a big output] by the resistance R of the whole element decreasing, and considering as the structure shown in drawing 3, although the technical problem which ΔR does not increase so much and does not serve as a big improvement in output occurred since there was no oxide magnetic film 31 in the conventional case. In this case, an electrode needs to remove the upside magnetization revolution control layer 2 and the upside oxide magnetic film 31, and needs to touch the metal magnetic film 32.

[0084] Drawing 4 is [*****] the magneto-resistive effect element 400 which consists of cascade screens of the metal

magnetic film 32 with which fixed-bed 3A touches a non-magnetic layer 4, and two oxide magnetic films 31 which are carrying out switched connection magnetically through the nonmagnetic membrane 33, when special. In drawing 4, switched connection of the oxide magnetic film 31 is magnetically carried out through a nonmagnetic membrane 33, and it does not carry out a magnetization revolution easily by the external magnetic field. When this and the metal magnetic film 32 join together magnetically, fixed-bed 3A is constituted as a whole. Furthermore, a new metal magnetic film may be prepared between the oxide magnetic film 31 and this nonmagnetic membrane 33, and the switched connection between two oxide magnetic films 31 through a nonmagnetic membrane 33 may be strengthened.

[0085] In addition, although not shown in drawing, the magnetization revolution control layer 2 may be further formed like drawing 1 - drawing 3 between a substrate 1 and the oxide magnetic film 31.

[0086] Although what was mentioned above uses an oxide magnetic film for the fixed bed, as shown in drawing 5 - drawing 8, it may use an oxide magnetic film for a free layer.

[0087] In drawing 5 A, free layer 5A has the advantage which it consists of the metal magnetic films 51 and the oxide magnetic films 52 which touch a non-magnetic layer 4, and bigger MR ratio than the case where all free layers are metal magnetic films is obtained, and can reduce the total thickness of the metal section of the whole element 500A. However, that the oxide magnetic film 52 indicates soft magnetism to be in this case is desirable. Moreover, although monolayer showed the fixed bed 3 by a diagram, as shown in drawing 5 B, the cascade screen of the metal magnetic film 32 and the oxide magnetic film 31 is sufficient.

[0088] If the element 600 of drawing 6 also makes thin to 2nm or less the oxide magnetic film 52 besides the advantage from which the same effect is acquired, the soft magnetic characteristics of the oxide magnetic film 52 are not strictly so required as the case of drawing 5.

[0089] As for the oxide magnetic film 52, in any case, it is desirable for resistance to be high.

[0090] Drawing 7 is the example of a configuration of the type with which pinning of the fixed bed 3 is carried out by the magnetization revolution control layer 2, and especially drawing 8 is characterized by fixed-bed 3B consisting of [metal magnetic film 32 / oxide magnetic film 31 / metal magnetic film 32]. In the case of drawing 7, MR ratio with the bigger oxide magnetization revolution control layer 2 is obtained, and when it is drawing 8, MR ratio with the big one where resistance of the oxide magnetic film 31 of the center of fixed-bed 3B is higher is obtained.

[0091] Although drawing 9 makes reverse the upper and lower sides of the configuration of drawing 8 and a free layer is used as a monolayer like the configuration of drawing 1 - drawing 3, in order to raise the soft magnetic characteristics of the free layer 5, the substrate layer 7 is formed.

[0092] Drawing 10 is the thing of a configuration of having used monolayer for the free layer on the basis of the configuration of drawing 8, and having formed the oxide nonmagnetic membrane 6 in the upper part. Moreover, in order to raise the property of the magnetization revolution control layer 2, the substrate layer 7 is formed. In this case, the effect that MR ratio becomes large is acquired by making flat the interface of the oxide nonmagnetic membrane 6 and the free layer 5 prepared in the upper part.

[0093] Although drawing 11 A carries out switched connection of the one magnetic layer (metal magnetic film 32) which touches the magnetization revolution control layer 2 on the basis of the configuration of drawing 10 and which will be rich a magnetic layer (metal magnetic film 32) magnetically like fixed-bed 3A of drawing 4 through a nonmagnetic membrane 33 and it is a thing, unlike drawing 4, the metal magnetic film 32 is used in this case. By making thickness of a nonmagnetic membrane 33 into a suitable value (for example, using Ru that thickness 0.6-0.8nm), it is possible to make this switched connection antiferromagnetism-like. The effect which heightens the pinning effect of the magnetization revolution control layer 2 by this is acquired.

[0094] Moreover, when this magneto-resistive effect element 1100 is used for a spin valve head by considering as antiferromagnetism-association, the effect that the bias magnetic field to the free layer 5 by the whole fixed-bed 3C can be reduced is acquired. In addition, unlike drawing 10, there is no oxide nonmagnetic membrane 6 on the free layer 5 in this case, but an oxide film may be prepared in the upper part as a cap, and a metaled protective coat may be prepared.

[0095] Drawing 12 is an element using what consists of a two-layer ferromagnetic (metal magnetic film 51) from which the thickness or the saturation magnetization in which free layer 5C carried out switched connection in antiferromagnetism through the nonmagnetic membrane 53 especially differs. Two ferromagnetics serve as anti-parallel through the nonmagnetic membrane 53, and if the magnetization by whole free layer 5C sets thickness of two magnetic films to d1 and d2, respectively and saturation magnetization is set to Ms1 and Ms2, respectively, it is set to Ms1 and d1-Ms2, and d2, and can make the demagnetization factor in the whole small. That sensitivity deteriorates, in the case of a magnetic resistance element or an arm head, if element width of face generally becomes small, a demagnetization factor becomes large, when it is a memory device, it will become the factor which makes the current of the word line in the case of flux reversal increase, but that technical problem is solved by considering as this structure.

- [0096] Drawing 13 tended to unite the element structure of drawing 12 with drawing 6, tends to insert the oxide magnetic film 52 in one side of the magnetic film of free layer 5D, and tends to obtain still bigger MR ratio.
- [0097] As a magnetization revolution control layer 2, there are Ir-Mn of an irregular alloy system, Rh-Mn, Ru-Mn, Cr-Pt-Mn, etc. as a metal membrane, and there is an advantage from which switched connection can be carried out to a magnetic film, and a process becomes simple by forming membranes in a magnetic field. When forming an element using these films, considering as the configuration of vertical reverse is desirable, and, as for drawing 1 and 2, it is desirable in drawing 3 to use for the upper magnetization revolution control layer 2. On the other hand, although nickel-Mn of an ordered alloy system, Pt-(Pd)-Mn, etc. need heat treatment for regulation-izing, it excels in thermal stability. When also using these for a magneto-resistive effect element generally, the configuration of vertical reverse is desirable and, as for drawing 1 and 2, it is desirable in drawing 3 to use for the upper magnetization revolution control layer 2. In addition, a Pt-Mn system -- the upper and lower sides -- although either could be used and it came, and it had the desirable features since [that the pinning effect was also large and] it was thermally stable, the element which used these metal membranes for the magnetization revolution control layer 2 had the defect from which big MR ratio is not obtained. Even if this invention compensates this defect and uses these metal system for the magnetization revolution control layer 2, it can obtain big MR ratio.
- [0098] when an oxide film was used as a magnetization revolution control layer 2, it mentioned above -- as -- 2 -- if there is an oxide-film-ized film of OX, NiO, and alpha-Fe₂O₃ grade and these are used, big MR ratio will be obtained, and bigger MR ratio is obtained by considering as the configuration of this invention. Since NiO has a technical problem in thermal stability a little, when it is made into alpha-Fe₂O₃ and a laminated structure, it is more desirable. (AB) Although 2OX films are excellent in the thermal resistance of itself, they need substrate heating at the time of membrane formation. (AB) In 2OX, A is an element with a large ionic radius, its rare earth elements, such as La, Pr, Nd, Sm, and Y, are desirable, transition metals of B with a small ionic radius are desirable, and the pinning effect of Fe is desirable especially as a certain magnetization revolution control layer to an elevated temperature.
- [0099] As a free layer 5 of the magnetic resistance element shown in drawing, the nickel-Co-Fe alloy is suitable. As an atomic composition ratio of a nickel-Co-Fe film, it is desirable to use the soft magnetism film of nickel-rich of $\text{Ni}_x\text{Co}_y\text{Fe}_z$ $0.6 \leq x \leq 0.90$, $0 \leq y \leq 0.40$, $0 \leq z \leq 0.3$ or the Co-rich film of $\text{Ni}_x\text{Co}_y\text{Fe}_z$ $0 \leq x \leq 0.40$, $0.2 \leq y \leq 0.950$, $0 \leq z \leq 0.5$. The film of these presentations has the low magnetostriction property (1×10^{-5}) demanded as a sensor or an object for MR heads.
- [0100] As thickness of the free layer 5, 1nm or more 10nm or less is good. If thickness is thick, MR ratio will fall by the shunt effect, but if too thin, soft magnetic characteristics will deteriorate. 2nm or more 7nm or less is more desirably good.
- [0101] As a metal magnetic film 32 of the fixed bed, materials, such as Co or Co-Fe, nickel-Fe, and a nickel-Fe-Co alloy, are excellent. Since it is good for obtaining MR ratio especially with big Co or Co-Fe alloy, it is desirable to use Co-rich for an interface with a non-magnetic layer 4.
- [0102] As an oxide magnetic film 31 of the fixed bed, MFe₂O₄ (one sort or two sorts or more of elements with which M is chosen from Fe, Co, and nickel) is desirable. These show ferromagnetism to an elevated temperature comparatively, and Co and nickel-rich have very high resistance compared with Fe-rich. Moreover, since Co-rich has the features that a magnetic anisotropy is large, the thing of a desired property is obtained by adjustment of these presentation ratios. What uses Fe₃O₄ as a principal component from a viewpoint of soft magnetic characteristics or saturation magnetization is desirable.
- [0103] Moreover, what uses CoFe₂O₄ with a large magnetic anisotropy and large coercive force as a principal component at the fixed beds 3, 3A, and 3B and 3C which consist of the metal magnetic film 32 and the oxide magnetic film 31 is desirable.
- [0104] It is desirable to use an oxide for a target as a method of producing the oxide magnetic film 31, when controlling thickness to a precision to 0.1nm order, and to form membranes by the spatter.
- [0105] Precise thickness control of 2OFe₃O₄ and CoFe₄ film is possible, and if the spatter of the above-mentioned case 3O₄, for example, Fe, or CoFe₂O₄ is carried out with inert gas, such as Ar gas, using the target used as a principal component, since it is not necessary to pass oxygen gas to the spatter interior of a room, it is possible to maintain a spatter room at a high vacuum.
- [0106] Even if it sometimes uses MFe₂O₄ for a target, O may fall out from the case where O in the made film (oxygen) decreases, and a target, O in a film may decrease, but if the spatter of a suitable quantity (10% or less is usually desirable at a division ratio with inactive sputtering gas) of the oxygen gas is added and carried out to sputtering gas in this case, a desired film presentation will be acquired.
- [0107] As another material of the fixed bed 3, the metal magnetic film 32 and its oxide can be used as an oxide

magnetic film 31. In this case, it is not necessary to newly prepare a sputtering target as an oxide magnetic film, and production becomes easy. Especially as a metal magnetic film 32, when a Co-Fe film is used, a Co-Fe-O film turns into the good oxide magnetic film 31.

[0108] At this time, there is a various method as the formation method of the oxide magnetic film 31. First, one forms the metal magnetic film 32 beforehand, and it is the method of oxidizing the front face of the metal magnetic film 32, after that. The method of oxidizing the front face of the metal magnetic film 32 has a plasma oxidation method, a natural oxidation method, a method of using a radical gun, a method using an ion gun, etc. In a vacuum chamber, a plasma oxidation method gives the potential difference of rf or DC for oxygen gas between a metal membrane front face and an electrode with a sink, generates the plasma between a film front face and an electrode, and oxidizes a metal membrane front face by the plasma. Although the damage on the front face of a metal membrane is also serious, the oxide film of high resistance is formed comparatively.

[0109] Although a natural oxidation method also has a method of exposing a metal membrane to atmospheric air once, in atmospheric air, the way a not fixed problem also has humidity, it introduces oxygen gas into a vacuum chamber more desirably at the pressure below atmospheric pressure, and oxidizes the front face of a metal membrane is good.

[0110] moreover, the method of the method using a radical gun irradiating the oxygen radical generated by discharge inside a gun on a metal membrane front face, and oxidizing -- it is -- comparatively -- a metal membrane -- a damage -- it is a method effective in oxidizing only a front face few.

[0111] Moreover, even if it is not radical and uses ion, a film front face can be oxidized. Although there are various types using the Kauffmann mold using a heat filament as the ion source and ECR discharge etc., all are effective in this invention. In this case, the seal of approval of the acceleration voltage is carried out, and the oxygen ion generated from the ion gun is thrown at a surface of metal. Since the damage of a metal membrane will become large as acceleration voltage if too not much high, it is good to consider as less than [200V] desirably below 500V at most.

[0112] The thickness of the whole fixed bed 3 has 1nm or more good 10nm or less.

[0113] Moreover, in order to enlarge MR ratio further, it is also effective to insert an interface magnetic layer in the interface of a ferromagnetic layer (the fixed bed 3 or free layer 5) and a non-magnetic layer 4. Although nickel-rich is good since soft magnetic characteristics are required for the free layer 5, considering as a high MR ratio is possible, without spoiling the **** soft magnetic characteristics which others make nickel-rich at the interface magnetic layer of the free layer 5 which touches a non-magnetic layer 4 using Co-rich. Moreover, it is desirable to use Co-rich for an interface with a non-magnetic layer 4 at the center of the free layer 5 using above-mentioned nickel-rich with structure like drawing 3. If the thickness of the interface magnetic layer of the free layer 5 is thick, since soft magnetic characteristics will deteriorate and the magnetic field sensitivity of MR ratio will fall, the thickness of an interface magnetic layer needs to set 2nm or less to 1.8nm or less desirably. Moreover, in order for this interface magnetic layer to work effectively, thickness at least 0.2nm or more is required, and its thickness 0.8nm or more is desirably good. As a material of an interface magnetic layer, Co or the Co-Fe alloy of Co high concentration is excellent.

[0114] Although the nonmagnetic membrane 33 of drawing 4 or drawing 11 and drawing 12, and the non-magnetic metal film that is easy to produce the switched connection between magnetic layers in the nonmagnetic membrane 53 of 13 may be desirable and Cu, Ag, and Au are sufficient, from the thermal stability of an interface, Ru, Rh, Ir, Re, etc. are more more desirable, and especially Ru is excellent. As a metal magnetic film in the case of preparing between the oxide magnetic film 31 and this nonmagnetic membrane 33, the metal magnetic film of Co-rich is desirable at ****4. It is possible to strengthen the switched connection between two oxide magnetic films 31 which minded the nonmagnetic membrane 33 by insertion of this metal magnetic film.

[0115] As a non-magnetic layer 4 between the free layer 5 and the fixed bed 3, although there are Cu, Ag, Au, Ru, etc., especially Cu is excellent. As thickness of a non-magnetic layer 4, in order to weaken the interaction between magnetic layers, at least 0.9nm or more is required. Moreover, since MR ratio will fall if a non-magnetic layer 4 becomes thick, thickness should set 10nm or less to 3nm or less desirably. Moreover, in the configuration of drawing 1 - drawing 3, when the thickness of this non-magnetic layer 4 is 3nm or less, if the surface smoothness of each class from the substrate 1 to this non-magnetic layer 4 is important and its surface smoothness is bad, between two magnetic layers (the metal magnetic film 32 and free layer 5) which should be magnetically separated by the non-magnetic layer 4, magnetic association will arise and deterioration of MR ratio and lowering of sensitivity will produce it. Therefore, as for the irregularity of the interface of a magnetic layer/non-magnetic layer, it is desirable that it is 0.5nm or less.

[0116] As a substrate 1, the comparatively smooth thing of front faces, such as glass, MgO and Si, and an aluminum₂O₃-TiC substrate, is used. In producing an MR head, the aluminum₂O₃-TiC substrate is suitable.

[0117] In addition, as the configuration method of each class described above, the sputtering method is suitable. Although there are the DC sputtering method, an RF sputtering method, the ion beam sputtering method, etc. as a

sputtering method, the magneto-resistive effect element of this invention is producible by any method.

[0118] A magneto-resistive effect mold arm head can be constituted using the magneto-resistive effect element of this invention which was described above. An example of the configuration of MR head 1400A of a hard film bias mold is shown in drawing 14 A as an example of an MR head. The MR element 9 consists of drawing 14 A so that it may be inserted into the shield gaps 11 and 14 of the upper part and the lower part. As shield gap material, insulator layers, such as aluminum $2O_3$, and SiO_2 , AlN , are used.

[0119] As the upper part and lower shields 10 and 15, they are nickel-Fe (-Co) and Co-Nb-Zr. Soft magnetism films, such as a Fe-Ta-N alloy, are used. A nickel-Fe (-Co) system is producible with plating, a Co-Nb-Zr system is excellent in corrosion resistance, and its controllability of an anisotropy is good. A Fe-Ta-N system is strong to elevated-temperature heat treatment, and is a field joint-right effect which uses a magnetization revolution control layer with the need of forming substrate temperature at an elevated temperature like an above-mentioned (AB) $2O_X$ system.

[0120] The bias magnetic field of the hard bias section 12 which consists of hard films, such as a Co-Pt alloy, is used for magnetic-domain control of the MR element 9. The MR element 9 is insulated with a shield 10 and 15 grades with the shield gaps 11 and 14, and resistance change of the MR element 9 is read by passing current through the lead section 13.

[0121] If the densification of a future hard disk drive is taken into consideration, there is the need of shortening record wavelength and it is necessary to shorten distance d during the shield shown in drawing 14 A for that purpose. For that purpose, it is desirable for it to be necessary to make the MR element 9 thin, and to be referred to as at least 20nm or less so that clearly from drawing 14 A. Since the magnetization revolution control layer 2 of an oxide is an insulator layer, it can be caught with a part of lower shield gap 11, and can be called structure suitable for this object rather than it calls it the MR element 9 substantially.

[0122] Moreover, in the MR element 9, in order to press down generating of a Barkhausen noise at the time of the magnetization revolution of a free layer, it is good [the easy axis of the fixed bed 3] to be constituted so that it may become the direction of a magnetic field and parallel which should be detected so that it may become vertical [the easy axis of drawing 1 and the free layer 5 of 2, 3, and 4] to the direction of a signal magnetic field which should be detected.

[0123] Although what was shown in drawing 14 A has the hard bias section 12, what is shown in drawing 14 B has antiferromagnetism bias section 12A instead of this. Although there is a problem to which a shield gap becomes narrow in connection with densification, the magnetic field from the hard bias section 12 is absorbed by the shield section, and the bias magnetic field to the free layer 5 of the MR element 9 becomes weak, there is the advantage by which this technical problem is solved with the structure of having this antiferromagnetism bias section 12A. However, it tends to form element 1400B that it shall be different in the antiferromagnetism bias section 12A. However, it tends to antiferromagnetism film of antiferromagnetism bias section 12A in this case, for example, it uses a PtMn system for the MR element 9, and should just use an IrMn system etc. for antiferromagnetism bias section 12A.

[0124] In addition, although the above explained the conventional horizontal-type GMR head, this invention is effective also to the GMR head of a vertical mold. It is characterized by a vertical mold GMR head passing current to parallel to a magnetic field to the direction of current being vertical to the magnetic field which a horizontal-type GMR head detects.

[0125] Another yoke mold arm head 1500 is indicated to be the shield mold of drawing 14 A and 14B to drawing 15 as an example of the magnetic head of this invention. In order that 16 may be the yoke which consisted of soft magnetism films which guide the signal magnetic field which should be detected for the MR element 9 and this yoke may usually use a conductive metal magnetic film in drawing 15, an insulator layer 17 is formed so that it may not short-circuit with the MR element 9. Moreover, in order to use a yoke 16, by sensitivity, it is inferior to the arm heads 1400A and 1400B of the type of drawing 14 A and 14B, but since this arm head 1500 does not need to place the MR element 9 into a shield gap like drawing 14 A and 14B, it is advantageous in narrow-gap[super-]-izing.

[0126] Since these magnetic heads 1400A, 1400B, and 1500 are excellent in playback sensitivity, if they carry out them which exceeds 2 40 Gb/inch will become possible.

[0127] Drawing 17 is an example of a memory device which used the magneto-resistive effect element of this invention. the object for information record with which the memory device 1700 was insulated in the magneto-resistive effect element 9 which has [the free layer / non-magnetic layer / fixed bed] of this invention, and the magneto-resistive effect element 9 -- a conductor -- the object for information read-out connected with the line (word line) 22, the magneto-resistive effect element 9, and the electrode 21 -- a conductor -- it has a line (sense line) 23. Although the thing of the structure of the film surface of the magneto-resistive effect element 9 of this invention of having an electrode 21 up and

down is shown by a diagram, it is good for right and left of the magneto-resistive effect element 9 also as structure of having an electrode. Moreover, a magnetization revolution control layer may be attached to the bottom of the fixed bed 3.

[0128] In drawing, magnetization of the free layer 5 of the magneto-resistive effect element 9 is reversed for current to a word line 22 by the sink and the magnetic field which this generates, and information is written in it. Again, playback passes current to a word line 22, reverses magnetization of the free layer 5 to it, and reads information for the resistance change at that time to it by the sense line 23. In this case, flux reversal of the fixed bed 3 is not performed, but only flux reversal of the free layer 5 is performed, and the direction of magnetization identifies "1" and "0" conditions by parallel or anti-parallel from the thing with the fixed bed 3 which resistance of the magneto-resistive effect element 9 differs.

[0129] In the above-mentioned case, are destructive reading by which information is erased in the case of information read-out, but Pass current to a word line 22, and the fixed bed 3 and the free layer 5 generate the magnetic field which starts flux reversal, and record information on the fixed bed 3, and read-out passes current weaker than the above to a word line 22. Destructive read is possible for it, if the flux reversal of the fixed bed 3 generates the magnetic field which does not start but starts only the flux reversal of the free layer 5 and "1" and "0" conditions are identified by the lifting and resistance change accompanying this only for the flux reversal of the free layer 5. However, since the reversal magnetic field from which it differs the object for the fixed beds 3 and for the free layers 5 in this case needs to be set up, actuation becomes a little complicated.

[0130] Two or more these magnetic-reluctance memory devices 1700 are arranged in the shape of a matrix, and if the synthetic magnetic field which generates a word line from a word line 22 as arrangement which intersects perpendicularly on each MR element 9 performs writing of the information on the MR element 9, and read-out, the so-called MRAM is constituted. Unlike the conventional semiconductor DRAM, this MRAM is nonvolatile, does not have a soft error, either, and is promising as next-generation solid-state memory.

[0131] [Example] The magneto-resistive effect element of this invention and a magneto-resistive effect mold arm head, and a magneto-resistive effect memory device are explained using a concrete example below.

[0132] (Example 1) The magneto-resistive effect element without the magnetization revolution control layer 2 was produced from the configuration shown in drawing 1 using multitarget sputtering equipment. For the free layers 5, the alloy target of $\text{Co}_{0.9}\text{Fe}_{0.1}$ was used for the substrate 1 for Cu as an object for the metal magnetic films 32 of the fixed bed 3 using Si, mainly using $\text{nickel}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ as an object for non-magnetic layers 4. Moreover, CoFe 2O_4 was used for the oxide magnetic films 31 of the fixed bed 3. After exhausting the inside of a vacuum chamber to 1×10^{-8} or less Torr(s), the sputtering method was used on the glass substrate with the sink so that Ar gas might be set to about 0.8 mTorr(s), and the magneto-resistive effect element of the configuration of the following example sample 1A was produced. Moreover, the conventional example sample which does not use CoFe 2O_4 for a comparison was also produced.

[0133] Example sample 1A $\text{NiFeCo}(5) / \text{Cu}(2) / \text{CoFe}(2) / \text{CoFe 2O}_4(5)$

(The inside of a parenthesis shows the thickness of each class per nm)

Thus, the seal of approval of the magnetic field of a maximum of 200 kA/m was carried out at the room temperature, and the direct-current 4 terminal method estimated the MR property of the produced magneto-resistive effect element. As a result, MR ratio succeeded in acquiring the high value of 16%. The conventional example sample which, on the other hand, does not use CoFe 2O_4 had large dispersion in a property, and that to which MR ratio also exceeds 10% was not obtained. MR ratio decides to be shown with the value of % below.

[0134] (Example 2) The magneto-resistive effect element 100 of a configuration of having been shown in drawing 1 using multitarget sputtering equipment was produced. NiO sintered at the target for magnetization revolution control layer 2 at the substrate 1 using Si, and $\alpha\text{-Fe}_2\text{O}_3$ and ABO_3 ($\text{A}=\text{La}$; $\text{B}=\text{Fe}$) -- moreover, $\text{Pt}_{0.5}\text{Mn}_{0.5}$ and $\text{Ir}_{0.2}\text{Mn}_{0.8}$ were used as an alloy target.

[0135] The alloy target of $\text{Co}_{0.9}\text{Fe}_{0.1}$ was used for the free layers 5 for Cu as the object for the interface magnetic films of the free layer 5, and an object for the metal magnetic films 32 of the fixed bed 3, mainly using $\text{nickel}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ as an object for non-magnetic layers 41. Moreover, Fe 3O_4 was used for the oxide magnetic films 31 of the fixed bed 3. After exhausting the inside of a vacuum chamber to 1×10^{-8} or less Torr(s), the sputtering method was used on the glass substrate with the sink so that Ar gas might be set to about 0.8 mTorr(s), and the magneto-resistive effect element of the following configuration was produced. Moreover, the sample which does not use Fe 3O_4 for a comparison was also produced (conventional example sample A-D).

The conventional example sample A $\text{NiFeCo}(3) / \text{CoFe}(1) / \text{Cu}(2) / \text{CoFe}(2.5) / \text{PtMn}(20)$
The conventional example sample B $\text{NiFeCo}(3) / \text{CoFe}(1) / \text{Cu}(2) / \text{CoFe}(2.5) / \text{IrMn}(15)$

The conventional example sample C NiO(10) / α -Fe₂O₃ (20) / CoFe(2.5)/Cu(2) / CoFe(1) / NiFeCo (3)
 The conventional example sample D LaFeO₃ (40) / CoFe(2.5)/Cu(2) / CoFe(1) / NiFeCo (3)
 Example sample 1 CoFe [NiFeCo(3) /] (1)/Cu(2) / CoFe(1) / Fe₃O₄ (1.5) / PtMn (20)
 Example sample 2 CoFe [NiFeCo(3) /] (1)/Cu(2) / CoFe(1) / Fe₃O₄ (1.5) / NiFeCo (3)
 example sample 3 NiO(10) / α -Fe₂O₃ (20) / Fe₃O₄ (1.5) / CoFe(1) / Cu(2) / CoFe(1) / NiFeCo (3)
 Example sample 4 LaFeO₃ (40) / Fe₃O₄(1.5)/CoFe(1) / Cu(2) / CoFe(1) / NiFeCo (3)

However, drawing 1 of the conventional example samples A and B and the example samples 1 and 2 is the structure of vertical reverse. Moreover, by the above-mentioned sample, NiFeCo(3) / CoFe (1) corresponds to the free layer 5, CoFe (2.5) corresponds to the fixed bed 3 in conventional example sample A-D, and CoFe (1)/Fe₃O₄ (1.5) corresponds to the fixed bed 3 with the example samples 1-4.

[0136] Thus, the seal of approval of the magnetic field of a maximum of 200 kA/m was carried out at the room temperature, and the direct-current 4 terminal method estimated the MR property of the produced magneto-resistive effect element. The pinning magnetic field of an element was set to H_p , and the measurement result was shown in (a table 1).

[0137]

[A table 1]

試料	MR比	H_p (kA/m)
従来例サンプル A	8	80
従来例サンプル B	11	40
従来例サンプル C	16	20
従来例サンプル D	12	45
実施例サンプル 1	13	80
実施例サンプル 2	14	40
実施例サンプル 3	19	40
実施例サンプル 4	15	50

[0138] Although MR ratio increased and the oxide magnetization revolution control layer 2 was used when conventional example sample A-D considered as this invention structure from the experimental result shown in (a table 1), it turns out that H_p is improved.

[0139] (Example 3) The magneto-resistive effect element 200 of the structure shown in drawing 2 using multitarget sputtering equipment was produced like the example 1. The oxide nonmagnetic membrane 6 produced 2Oaluminum3 film by the reactive sputtering by the mixed gas of Ar and O₂ using aluminum target. The magneto-resistive effect element 200 as shown in drawing 2 was produced.

[0140] example sample 5 PtMn(20) / Fe₃O₄ (1.5) / CoFe -- (1) / Cu(2) / CoFe(1) / NiFeCo(3) / aluminum 2O3 (2)
 Example sample 6 CoFe [aluminum2O3(2) / NiFeCo(3) /] (1)/Cu(2) / CoFe(1) / Fe₃O₄ (1.5) / IrMn (15)

However, the example sample 6 has structure of reverse with drawing 2. Thus, the seal of approval of the magnetic field of a maximum of 200 kA/m was carried out at the room temperature, and the direct-current 4 terminal method estimated the MR property of the produced magneto-resistive effect element. The pinning magnetic field of an element was set to H_p , and the measurement result was shown in a table 2.

[0141]

[A table 2]

試料	MR比	H_p (kA/m)
実施例サンプル 5	15	80
実施例サンプル 6	16	40

[0142] When the example samples 1 and 2 of the result of (a table 2) and a table 1 are compared, it turns out that MR ratio is improved.

[0143] (Example 4) The magneto-resistive effect elements 500A and 700 of a configuration of having been shown in drawing 5 B and drawing 7 using multitarget sputtering equipment were produced. It considered as the target at the substrate 1 using Si, and as an object for non-magnetic layers 4, nickel_{0.68}Fe_{0.20}Co_{0.12} was used for the metal

magnetic films 51 of the free layers 5A and 5B, and Fe 3O₄ was used for the oxide magnetic films 52 for Cu.

[0144] For the fixed beds 3 of drawing 5 B, using the cascade screen of Co_{0.9}Fe_{0.1} and CoFe 2O₄, Co_{0.9}Fe_{0.1} was used for fixed-bed 3D of drawing 7, and alpha-Fe 2O₃ was used for the magnetization revolution control layers 2.

[0145] After exhausting the inside of a vacuum chamber to 1x10 to 8 or less Torr, the sputtering method was used on the glass substrate with the sink so that Ar gas might be set to about 0.8 mTorr(s), and the magneto-resistive effect elements 500B and 700 of the following configuration were produced.

[0146] Example sample 7 nickel_{0.68}Fe_{0.20}Co [CoFe₂O₄ (50) / Co_{0.9}Fe_{0.1}(2) / Cu(2) /]0.12 (4)/Fe 3O₄ (1) nickel_{0.68}Fe_{0.20}Co0.12 (3)

Thus, the seal of approval of the magnetic field of a maximum of 200 kA/m was carried out at the room temperature, and the direct-current 4 terminal method estimated the MR property of the produced magneto-resistive effect elements 500B and 700. The pinning magnetic field of an element was set to H_p, and the measurement result was shown in (a table 3).

[0147]

[A table 3]

試料	MR比	H _p (kA/m)
実施例サンプル 7	12	35
実施例サンプル 8	13	40

[0148] It is effective to use the magnetic film which carried out switched connection of the fixed bed 3 through nonmagnetic membranes, such as Ru, for improving further the property of H_p shown in (a table 3).

[0149] In this case, it also becomes possible to reduce the thickness of the oxide magnetic film 31. Moreover, although the NiFeCo film is used for free layer 5B from a viewpoint of sensitivity in the above-mentioned example, if CoFe is used, still bigger MR ratio will be obtained.

[0150] Ru was further used for the target from this viewpoint, and the magneto-resistive effect element of the following configurations was produced similarly.

[0151] Example sample 9 Co_{0.9}Fe [alpha-Fe 2O₃ (30) / Co_{0.9}Fe_{0.1}(2) / Ru(0.7)/CoFe(2) / Cu(2) /]0.1 (4)/Fe 3O₄ (1) Thus, the seal of approval of the magnetic field of a maximum of 200 kA/m was carried out at the room temperature, and the direct-current 4 terminal method estimated the MR property of the produced magneto-resistive effect element. The pinning magnetic field of an element was set to H_p, and the measurement result was shown in (a table 4).

[0152]

[A table 4]

試料	MR比	H _p (kA/m)
実施例サンプル 9	16	60

[0153] Thus, it turned out that MR ratio and H_p are further improvable.

[0154] (Example 5) The magneto-resistive effect element 700,800 of a configuration of having been shown in drawing 7 and drawing 8 using multitarget sputtering equipment was produced. It considered as the target at the substrate 1 using Si, and as an object for non-magnetic layers 4, nickel_{0.8}Fe_{0.2} and Co_{0.9}Fe_{0.1} were used for the metal magnetic films 51 of free layer 5B, and Fe 3O₄ was used for the oxide magnetic films 52 for Cu. Co_{0.9}Fe_{0.1} was used for fixed-bed 3D of drawing 7, alpha-Fe 2O₃ was used for the magnetization revolution control layer 2, and Ta was used [Co_{0.9}Fe_{0.1} and Fe₃O₄] for fixed-bed 3B of drawing 8 for PtMn as a buffer layer between PtMn and a substrate 1 for the magnetization revolution control layers 2 again. After exhausting the inside of a vacuum chamber to 1x10 to 8 or less Torr, the sputtering method was used on the glass substrate with the sink so that Ar gas might be set to about 0.8 mTorr (s), and the magneto-resistive effect element of the following configuration was produced.

[0155] Example sample 10 Alpha-Fe 2O₃ (50) / Co_{0.9}Fe_{0.1}(2) / Cu(2) / Co_{0.9}Fe_{0.1}(2) / Fe₃O₄(1) / nickel_{0.8}Fe_{0.2} (3)

Example sample 11 Ta(5) / PtMn(15) / Co_{0.9}Fe_{0.1}(2) / Fe₃O₄(1) / Co_{0.9}Fe_{0.1}(2) / Cu(2) / Co_{0.9}Fe_{0.1} (5)

Example sample 12 Co_{0.9}Fe [Ta(5) / PtMn(15) / Co_{0.9}Fe_{0.1}(2) / Fe₃O₄(1) / Co_{0.9}Fe_{0.1}(2) / Cu(2) /]0.1 (2)/Fe 3O₄ (1) / nickel_{0.8}Fe_{0.2} (3)

Thus, the seal of approval of the magnetic field of a maximum of 200 kA/m was carried out at the room temperature, and the direct-current 4 terminal method estimated the MR property of the produced magneto-resistive effect element. The pinning magnetic field of an element was set to H_p, and the measurement result was shown in (a table 5).

[0156]

[A table 5]

試料	MR比	Hp (kA/m)
実施例サンプル 10	20	40
実施例サンプル 11	17	50
実施例サンプル 12	19	45

[0157] (Example 6) The magneto-resistive effect element 400 of the structure shown in drawing 4 using multitarget sputtering equipment was produced.

[0158] For the free layers 5, the alloy target of $\text{Co}_{0.9}\text{Fe}_{0.1}$ was used for the substrate 1 for Cu using Si as an object for the metal magnetic films 32 of fixed-bed 3A, mainly using nickel $\text{Ni}_{0.68}\text{Fe}_{0.20}\text{Co}_{0.12}$ as an object for non-magnetic layers 4. Moreover, Fe_3O_4 was used for the oxide magnetic films 31 of fixed-bed 3A. After exhausting the inside of a vacuum chamber to 1×10^{-8} or less Torr, the sputtering method was used on the glass substrate with the sink so that Ar gas might be set to about 0.8 mTorr(s), and the magneto-resistive effect element of the following configuration was produced.

[0159] Example sample 13 $\text{NiFeCo}(4) / \text{Cu}(2) / \text{CoFe}(2) / \text{Fe}_3\text{O}_4(2) / \text{Ru}(0.7) / \text{Fe}_3\text{O}_4(3)$

Example sample 14 $\text{CoFe} [\text{CoFe} / \text{NiFeCo}(4) / \text{Cu}(2) / (2) / \text{Fe}_3\text{O}_4(2) / \text{CoFe}(2) / \text{Ru}(0.7) /] (2) / \text{Fe}_3\text{O}_4(3)$

Thus, the seal of approval of the magnetic field of a maximum of 200 kA/m was carried out at the room temperature, and the direct-current 4 terminal method estimated the MR property of the produced magneto-resistive effect element. The measurement result was shown in (a table 6).

[0160]

[A table 6]

試料	MR比	Hp (kA/m)
実施例サンプル 13	13	20
実施例サンプル 14	13	30

[0161] Big MR ratios are both and it turned out with the example sample 14 that bigger Hp is obtained.

[0162] By adding PtMn to Fe_3O_4 of the example samples 13 and 14 (3) as a magnetization revolution control layer further showed that Hp became still larger with about 60 and 80 kA/m, respectively.

[0163] (Example 7) Next, the magneto-resistive effect element of the example samples 1, 5, and 10 of this invention was used as a MR element 9, MR head 1400A as shown in drawing 14 A was constituted, and the property was evaluated. In this case, aluminum 2O_3 was used for the shield gaps 11 and 14 at a shield 10 and 15 material using nickel $\text{Ni}_{0.8}\text{Fe}_{0.2}$ alloy, using an aluminum 2O_3 -TiC substrate as a substrate.

[0164] Moreover, in the hard bias section 12, the lead section 13 consisted of Au(s) using the Co-Pt alloy.

[0165] Moreover, the anisotropy was given to the magnetic film so that it might become vertical to the direction of a signal magnetic field which the easy direction of magnetization of the free layer 5 should detect, and it might become the direction of a signal magnetic field and parallel which the direction of the easy axis of the fixed bed 3 should detect. After it heat-treated this method at 280 degrees C among the magnetic field and it specified the easy direction of the fixed bed 3 first after creating a magneto-resistive effect element, further, it was heat-treated at 200 degrees C, specified the easy shaft of the free layer 5, and performed it.

[0166] The sink and the AC signal magnetic field of about 3 kA/m were impressed to these arm heads for a direct current as sense current, the output of an arm head was evaluated, and it compared with the output of the arm head which used the magneto-resistive effect element of the conventional example sample A for MR element section 9, and made similarly the output of the MR head using MR element of this invention as an experiment. The result is shown below.

[0167]

[A table 7]

試作ヘッド	MR素子部	相対出力 (dB)
従来例 H-A	A	0
実施例 H-1	1	+4
実施例 H-5	5	+5
実施例 H-10	10	+6

[0168] Thus, it turned out that a big output is obtained as compared with the thing of the former [magnetic head / this invention].

[0169] (Example 8) By the same method as an example 1, the magnetic resistance element 300 of the dual structure shown in drawing 3 was created.

[0170] example sample 15 PtMn(20) / Fe₃O₄ (1.5) / CoFe -- CoFe [(1) / Cu(2) / CoFe(1) / NiFeCo(3) /] (1)/Cu(2) / CoFe(1) / Fe₃O₄ (1.5) / PtMn (20)
example sample 16 NiO (10) / alpha-Fe₂O₃ (20) / Fe₃O₄ (1.5) / CoFe -- CoFe [(1) / Cu(2) / CoFe(1) / NiFeCo(3) /] (1)/Cu(2) / CoFe(1) / Fe₃O₄ (1.5) / IrMn (15)

The MR effect was measured by the same method as an example 1 about the above magneto-resistive effect element.

[0171] The result is shown in a table 8.

[0172]

[A table 8]

試料	MR比 (%)	Hp(kA/m)
実施例サンプル 15	22	80
実施例サンプル 16	28	40

[0173] It turns out that very bigger MR ratio than a table is obtained.

[0174] (Example 9) The yoke mold arm head 1500 shown in drawing 15 using MR element of the above-mentioned example sample 15 was produced. In this case, the aluminum-O super-thin film with a thickness of 2nm produced by the plasma oxidation method was used for the insulator layer 17 of drawing 15. Moreover, the CoNbZr system amorphous alloy film of high permeability was used for the yoke 16. Thus, when the output of the produced arm head and the head output using MR element of the conventional example sample A of the table 1 of an example 1 were measured, it turned out that about +6dB output rise is realized.

[0175] (Example 10) The magneto-resistive effect element 900 shown in drawing 9 was created using the same sputtering system as an example 1. In this case, using Si which has about 100nm thermal oxidation film, as a substrate layer 7, Co_{0.9}Fe_{0.1} was used as a metal magnetic film 32 of Ta, the free layer 5, and fixed-bed 3B, and Pt_{0.5}Mn_{0.5} film was used for the substrate 1 as Cu and a magnetization revolution control layer 2 as a non-magnetic layer 4 on the front face. After exhausting the inside of a vacuum chamber until it was set to 1x10 to 8 or less Torrs, the flow rate was adjusted exhausting so that Ar gas might be set to about 0.8 mTorr(s). After forming Ta (5nm) film on a substrate 1 first, sequential formation of freedom layer 5Co_{0.9}Fe_{0.1} (2nm), non-magnetic layer 4Cu (2nm), and metal magnetic film 32Co_{0.9}Fe_{0.1} (3nm) was carried out by the spatter as the 1st process. next, spatter discharge is once suspended as the 2nd process -- making -- Ar gas -- about [in addition,] -- one eighth of oxygen gas -- a sink and a radical gun -- about 100 -- the power of W was switched on, the oxygen radical was generated, it was irradiated on the surface of the metal membrane, about 1nm of front faces of a metal magnetic film was oxidized, and the oxide magnetic film 31 was formed.

[0176] Next, after once stopping the gas flow and suspending discharge as the 3rd process, Ar gas was introduced again and Co_{0.9}Fe_{0.1} (2nm) was formed by the sputtering method as a metal magnetic film 32.

[0177] Furthermore, Pt_{0.5}Mn_{0.5} (20nm) film was formed by the sputtering method as a magnetization revolution control layer 2 as the 4th process. Finally Ta oxide film was formed in the front face as an oxide nonmagnetic membrane 6. Then, the sample was held in temperature of 260 degrees C for 3 hours, impressing the magnetic field of 1kOe in a vacuum further. Moreover, as a conventional example sample E, except that there was no 2nd process of the above, it completely created like the example sample 17.

[0178] example sample 17 Ta(5) / Co_{0.9}Fe_{0.1}(2) / Cu(2) / Co_{0.9}Fe_{0.1}(2) / Co-Fe-O(1) / Co_{0.9}Fe_{0.1}(2) / Pt_{0.5}Mn_{0.5} (20) / Ta-O(3 --) -- (before the thickness of Co-Fe-O oxidizes, it is shown)
the conventional example sample E Fe_{0.1} (2)/Cu(2) / Co_{0.9}Fe_{0.1}(5) / Pt_{0.5}Ta(5) / Co_{0.9}Mn_{0.5} (20)/-- Ta-O (3) --
In addition, although the above explained the example sample 17 using the method using a radical gun as a method of oxidizing the metal magnetic film 32, only a means by which others completely created an oxide similarly also created the film using other methods.

[0179] when a natural oxidation method is used, once the 1st process completely creates by the same method as the example sample 17 and exhausts the inside of a chamber after that, it introduces oxygen gas until the inside of a chamber is set to about 20 Torr(s) as the 2nd process, and is suitable -- time amount maintenance was carried out and 1nm of front faces of Co_{0.9}Fe_{0.1} film was oxidized like the example sample 17. Next, the vacuum chamber was exhausted until it was again set to 1x10 to 8 or less Torrs, and the example sample 18 of the completely same

configuration as the example sample 17 was created through the 3rd and 4th process and heat treatment. [0180] In using a plasma oxidation method, once creating by the same method as the example sample 17 and exhausting the inside of a chamber as the 2nd process after that, oxygen gas was introduced until it became 3mTorr degree, rf power of 0.01 W/cm² was impressed to the substrate electrode-holder side, and the metal magnetic film front face was oxidized. Next, the vacuum chamber was exhausted until it was again set to 1x10 to 8 or less Torrs, and the example sample 19 of the completely same configuration as the example sample 17 was created through the 3rd and 4th process and heat treatment.

[0181] Moreover, as a method using an ion gun, the ion gun which used the ECR plasma as an ion gun was used. Once the 1st process's completely creating by the same method as the example sample 17 and exhausting the inside of a chamber after that, 2GHz microwave is introduced into an ion gun as the 2nd process, and they are 4sccm(s) about oxygen gas. Ar gas was passed 0.5 sccms and the plasma was generated in the ion gun. Oxygen gas was pulled out with the acceleration voltage of about 50 V from this plasma, and the metal magnetic film front face was irradiated. Next, the vacuum chamber was exhausted until it was again set to 1x10 to 8 or less Torrs, and the example sample 20 of the completely same configuration as the example sample 17 was created through the 3rd and 4th process and heat treatment.

[0182] Next, others also created the film created by the same method as the example sample 17, using a reactive-sputtering method as a method of forming an oxide magnetic film. In this case, after creating metal magnetic film Co_{0.9}Fe_{0.1} (2nm) at the 1st process, in the chamber, oxygen gas and Ar gas were introduced until it was set to 0.8mTorr(s) at a rate of 8:2, sputtering of Co_{0.9}Fe_{0.1} (2nm) was carried out, and the Co-Fe-O film was formed so that it might become the almost same thickness as the example sample 17. The example sample 21 of the completely same configuration as the example sample 17 was created through the 3rd and 4th process and heat treatment like the example sample 17 after that.

[0183] Thus, the seal of approval of the magnetic field of 400 kA/m was carried out for the magneto-resistive effect element of created this invention at the room temperature, and the magneto-resistive effect was evaluated. The result is shown in a table 9.

[0184]

[A table 9]

試料	MR比(%)	Hp (kA/m)
実施例サンプル 17	13	78
実施例サンプル 18	13.5	60
実施例サンプル 19	12	75
実施例サンプル 20	12.8	70
実施例サンプル 21	13.3	68
従来例サンプル E	8	75

[0185] As shown in (a table 9), the example samples 17-21 of this invention are understood that MR ratio is large equal by Hp compared with the conventional example sample E.

[0186] (Example 11) The magneto-resistive effect element 1000 shown in drawing 10 was created using the same sputtering system as an example 10. Drawing 10 is the same except having made the order of a laminating of freedom layer 5 / non-magnetic layer 4 / fixed-bed 3B / magnetization revolution control layer 2 into reverse by drawing 9.

[0187] Moreover, it can create by the same method as drawing 9 only by the sequence of a process changing also about the creation method. In the case of this example, the magneto-resistive effect element of the following configurations was created as nickel_{0.8}Fe_{0.2}/Co cascade screen and fixed-bed 3B as Si with a thermal oxidation film, and a free layer 5 as a substrate 1, using Pt_{0.5}Mn_{0.5} film as Co_{0.8}Fe_{0.2}/Co-Fe-O/Co_{0.8}Fe_{0.2} film and a magnetization revolution control layer 2. In addition, the Co-Fe-O film was formed by the method using a radical gun like the example sample 17 in this case. Thus, the same method as an example 10 estimated the created example sample 22 and the conventional example sample F which does not have the oxide magnetic film 31 for a comparison.

[0188] The result is shown in a table 10.

[0189] Example sample 22 Co_{0.8}Fe [Ta(5) / Pt_{0.5}Mn_{0.5} (15) / Co_{0.8}Fe_{0.2}(2) / Co-Fe-O(1) /]0.2 (2)/Cu(2) / Co (0.5) / nickel_{0.8}Fe_{0.2}(3) / Ta-O (3) (before the thickness of Co-Fe-O oxidizes, it is shown)
The conventional example sample F Co_{0.8}Fe [Ta(5) / Pt_{0.5}Mn_{0.5} (15) /]0.2 (5)/Cu(2) / Co (0.5) / nickel_{0.8}Fe_{0.2}(3) / Ta-O (3)

[0190]

[A table 10]

試料	MR比(%)	Hp (kA/m)
実施例サンプル 22	15	67
従来例サンプル F	9	66

[0191] As shown in (a table 10), the example sample 22 of this invention is understood that MR ratio is large compared with the conventional example sample F.

[0192] (Example 12) Magneto-resistive effect element 1100A shown in drawing 11 A was created using the same sputtering system as an example 10. Drawing 11 A is the case where fixed-bed 3C is having the so-called laminating ferry (synthetic antiferromagnet) structure. By drawing 11 A, Ru is usually used for a nonmagnetic membrane 33. When a nonmagnetic membrane 33 is the thickness which is 0.4nm - 1 nm, antiferromagnetism-switched connection arises in the metal magnetic film 32 which touched this. Since this switched connection magnetic field is dramatically strong, the reversal magnetic field of fixed-bed 3C becomes very large after all. Since the nonmagnetic membrane 33 of the configuration of magneto-resistive effect element 1100A of drawing 11 A only increases compared with drawing 9 fundamentally, a part of process only increases and the manufacture method of this invention is also effective. In the case of this example, the magneto-resistive effect element of the following configurations was created as a nickel_{0.8}Fe_{0.2}/Co cascade screen and fixed-bed 3C as Si with a thermal oxidation film, and a free layer 5 as a substrate 1, using Ir_{0.2}Mn_{0.8} film or alpha-Fe₂O₃ film as Co_{0.9}Fe_{0.1}(2) / Co-Fe-O(1) / Co_{0.9}Fe_{0.1}(2) film, and a magnetization revolution control layer 2.

[0193] In addition, the Co-Fe-O film was formed by the method using a radical gun like the example sample 17 in this case. Thus, the same method as an example 10 estimated the created example samples 23 and 24 and the conventional example sample G which does not have the oxide magnetic film 32 for a comparison. The result is shown in (a table 11).

[0194] Example sample 23 Co_{0.9}Fe [Ta(3) / nickel_{0.8}Fe_{0.2}(5) / Ir_{0.2}Mn_{0.8}(10) / Co_{0.9}Fe_{0.1}(2) / Ru(0.7)/Co_{0.9}Fe_{0.1}(2) / Co-Fe-O(1) /]0.1 (2)/Cu(2) / Co (0.5) / nickel_{0.8}Fe_{0.2}(3) / Ta-O (3) (Before the thickness of Co-Fe-O oxidizes, it is shown)

Example sample 24 Co_{0.9}Fe [alpha-Fe₂O₃ (20) / Co_{0.9}Fe_{0.1}(2) / Ru(0.7)/Co_{0.9}Fe_{0.1}(2) / Co-Fe-O(1) /]0.1 (2)/Cu(2) / Co (0.5) / nickel_{0.8}Fe_{0.2}(3) / Ta-O (3)

The conventional example sample G Ta(3) / nickel_{0.8}Fe_{0.2}(5) / Ir_{0.2}Mn_{0.8}(10) / Co_{0.9}Fe_{0.1}(2) / Ru(0.7)/Co_{0.9}Fe_{0.1}(2)/Cu(2) / Co (0.5) / nickel_{0.8}Fe_{0.2}(3) / Ta-O (3)

[0195]

[A table 11]

試料	MR比(%)	Hp (kA/m)
実施例サンプル 23	15	100
実施例サンプル 24	18	60
従来例サンプル G	9	95

[0196] As shown in (a table 11), the example samples 23 and 24 of this invention are understood that MR ratio is large compared with the conventional example sample G. Moreover, although Hp becomes a little small when 2Oalpha-Fe 3 film is used for the magnetization revolution control layer 2, bigger MR ratio is obtained.

[0197] (Example 13) The magneto-resistive effect element 1000 of a configuration of having been shown in drawing 10 below was created by the same method as an example 1. However, two ferromagnetic layers (laminating ferry free layer) from which the thickness or the saturation magnetization which carried out switched connection to the free layer 5 in antiferromagnetism through the non-magnetic layer 4 (Ru in this case) in this case differs are used. A laminating ferry free layer is effective in lowering the thickness of a free layer to the difference of the thickness (magnetization) of two free layers substantially, and when an arm head is created, an effect is in high sensitivity-ization. In this example, Co_{0.9}Fe_{0.1} film was used as a ferromagnetic of the free layer 5. The configuration of the created film is shown below. In this case, it considered as the oxide magnetic film 31, and using 3OFe₄ film, the Pt_{0.5}Mn_{0.5}(20) film was used as a Co_{0.9}Fe_{0.1}(2) film and a flux reversal control layer 2, and Cu was used for the metal magnetic film 32 of fixed-bed 3B as a non-magnetic layer 4.

[0198] example sample 25 Co_{0.9}Fe [Ta(5) / Pt_{0.5}Mn_{0.5}(20) / Co_{0.9}Fe_{0.1}(1) / Fe₃O₄(1.5)/Co_{0.9}Fe_{0.1}(2) / Cu(2) /] 0.1 (2)/Fe₃O₄(1)/Co_{0.9}Fe_{0.1}(3) / Ru (0.7) / Co_{0.9}Fe_{0.1}(4)/-- Ta-O (3) --

http://www4.ipdl.jpo.go.jp/cgi-bin/tran_web.cgi_ejje

example sample 26 Co_{0.9}Fe [Ta(5) / Pt_{0.5}Mn_{0.5} (20) / Co_{0.9}Fe_{0.1}(1) / Fe₃O₄(1.5)/Co_{0.9}Fe_{0.1}(2) / Cu(2) /]0.1 (2)/Fe
3O₄ (1)/Co_{0.9}Fe_{0.1}(2) / Ru (0.7) / Co_{0.9}Fe_{0.1} (3)/-- Ta-O (3) --
the conventional example sample H Co_{0.9}Fe [Ta(5) / Pt_{0.5}Mn_{0.5} (20) /]0.1 (3)/Cu (2)/Co_{0.9}Fe_{0.1}(5) / Ru (0.7) /
Co_{0.9}Fe_{0.1} (4)/-- Ta-O (3) --

It used as a MR element 9, MR head 1400A as shown in drawing 14 A was constituted, and the property was evaluated.
In this case, aluminum 2O₃ was used for the shield gaps 11 and 14 at a shield 10 and 15 material using nickel_{0.8}Fe_{0.2}
alloy, using an aluminum₂O₃-TiC substrate as a substrate.

[0199] Moreover, in the hard bias section 12, the lead section 13 consisted of Au(s) using the Co-Pt alloy.
[0200] Moreover, the anisotropy was given to the magnetic film so that it might become vertical to the direction of a
signal magnetic field which the easy direction of magnetization of the free layer 5 should detect, and it might become
the direction of a signal magnetic field and parallel which the direction of the easy axis of the fixed bed 3 should detect.
After it heat-treated this method at 280 degrees C among the magnetic field and it specified the easy direction of the
fixed bed 3 first after creating a magneto-resistive effect element, further, it was heat-treated at 200 degrees C, specified
the easy shaft of the free layer 5, and performed it.

[0201] The sink and the AC signal magnetic field of about 3 kA/m were impressed to these arm heads for a direct
current as sense current, the output of an arm head was evaluated, and it compared with the output of the arm head
which used the magneto-resistive effect element of the conventional example sample A for MR element section 9, and
made similarly the output of the MR head using MR element of this invention as an experiment. The result is shown
below.

[0202]

[A table 12]

試作ヘッド	MR素子部	相対出力 (dB)
従来例 H-H	H	0
実施例 H-25	15	+6
実施例 H-26	16	+7

[0203] Thus, it turned out that a big output is obtained as compared with the thing of the former [magnetic head / this
invention].

[0204] (Example 14) Magneto-resistive effect element 1100A of a configuration of having been shown in drawing 11 A
below was created by the same method as an example 1. In this example, Co_{0.9}Fe_{0.1} film was used as a ferromagnetic
of the free layer 5. The configuration of the created film is shown below. In this case, it considered as the oxide
magnetic film 31, and using 3OFe₄ film, Pt_{0.5}Mn_{0.5} film was used as Co_{0.9}Fe_{0.1} film and a flux reversal control layer
2, Cu was used for the metal magnetic film 32 as a non-magnetic layer 4, Ru was used as a nonmagnetic membrane 33
for switched connection, and Ta was used as an object for protective coats. The configuration of the produced film is as
follows.

[0205] Example sample 27 Ta(5) / Pt_{0.5}Mn_{0.5} (15) / Co_{0.9}Fe_{0.1}(2) / Ru(0.7)/Co_{0.9}Fe_{0.1}(2) / Fe₃O₄(1.2)/Co_{0.9}Fe_{0.1}
(2) / Cu(2) / Co_{0.9}Fe_{0.1}(2) / Ta-O (3)

Example sample 28 Ta(3) / Pt_{0.5}Mn_{0.5} (15) / Co_{0.9}Fe_{0.1}(2) / Ru(0.7)/Co_{0.9}Fe_{0.1} (2) / Fe₃O₄(1) / Co_{0.9}Fe_{0.1} (2) / Cu
(2) / Co_{0.9}Fe_{0.1}(2) / Ta-O (3)

The conventional example sample I Ta(5) / Pt_{0.5}Mn_{0.5} (15) / Co_{0.9}Fe_{0.1}(2) / Ru(0.7)/Co_{0.9}Fe_{0.1} Co_{0.9}Fe [(2) /]0.1
(2)/Cu (2) /Co_{0.9}Fe_{0.1}(2) / Ta-O (3)

Thus, the magnetic head was produced like the example 13 using produced MR element.

[0206] The sink and the AC signal magnetic field of about 3 kA/m were impressed to these arm heads for a direct
current as sense current, the output of both arm heads was evaluated, and it compared with the output of the arm head
which used the magneto-resistive effect element of the conventional example sample I for the MR element 9, and made
similarly the output of the MR head using MR element of this invention as an experiment. The result is shown in (a
table 13).

[0207]

[A table 13]

試作ヘッド	MR素子部	相対出力 (dB)
従来例 H-I	I	0
実施例 H-27	17	+8
実施例 H-28	18	+8

[0208] Thus, it turned out that a big output is obtained as compared with the thing of the former [magnetic head / this invention].

[0209] When the HDD drive 1600 of a configuration of having been shown in drawing 16 using these magnetic heads 1400A, 1400B, and 1500 was made as an experiment, it turned out that 20 Gb/inch two or more recording density can be attained.

[0210] (Example 15) Magneto-resistive effect element 1100A of a configuration of having been shown in drawing 11 A which has the structure of examples 13 and 14 next was created. In this example, nickel_{0.68}Fe_{0.2}Co_{0.12} film is used as a ferromagnetic of the free layer 5. As an oxide magnetic film 31, Fe_{0.8}aluminum 0.2 and Fe_{0.8}Si_{0.2} are used for a target, and it is FeAlO at reactive sputtering. What was used as the FeSiO film is used. Pt_{0.5}Mn_{0.5} film was used as Co_{0.9}Fe_{0.1} film and a flux reversal control layer 2, and Ta was used for the metal magnetic film 32 as Ru and an object for protective coats as Cu and a nonmagnetic membrane 33 for switched connection as a non-magnetic layer 4. The configuration of the created film is shown below.

[0211] Example sample 29 Ta(3) / Pt_{0.5}Mn_{0.5} (15) / Co_{0.9}Fe_{0.1}(3) / Ru(0.7)/Co_{0.9}Fe_{0.1}(2) / FeAlO(1) / Co_{0.9}Fe_{0.1} (2) / Cu(2.2)/NiOFeCo(3) / Ru (0.7) / NiFeCo(2) / Ta (3)

Example sample 30 Ta(3) / Pt_{0.5}Mn_{0.5} (15) / Co_{0.9}Fe_{0.1}(3) / Ru(0.7)/Co_{0.9}Fe_{0.1}(2) / FeSiO(1) / Co_{0.9}Fe_{0.1} (2) / Cu (2.2)/NiOFeCo(3) / Ru (0.7) / NiFeCo(2) / Ta (3)

After having carried out patterning of the magneto-resistive effect element which carried out in this way and was created to 0.5-micrometer angle with reference to drawing 17, having attached the electrode 21 which changes from Cu/Pt to membranous right and left, constituting the sense line 23 and insulating these with aluminum 2O₃, the word line 22 which consists of Cu(s) was formed on it, and the magneto-resistive effect memory device 1700 was created.

[0212] Flux reversal of the free layer 5 which passes current to a word line 22 and changes from NiFeCo/Ru/NiFeCo to it is carried out, information is written, and it is *****. Next, even if it measured resistance change of a sink and a sense line 23 for current in the same direction as a word line 22, change was not observed, but when current was passed to hard flow, a clear resistance change was observed by the sense line 23. Thus, it turned out that a memory device 1700 can be constituted using the magnetic resistance element 9 of this invention.

[0213] (Example 16) The magneto-resistive effect element 1300 of a configuration of having been shown in drawing 13 which inserted the oxide magnetic film 52 also in free layer 5D next was created after attaching the Cu/Pt film for electrodes on a substrate. In this example, using nickel_{0.68}Fe_{0.2}Co_{0.12} film as a metal magnetic film 51 of free layer 5D, Pt_{0.5}Mn_{0.5} film was used as Co_{0.9}Fe_{0.1} film and a flux reversal control layer 2, Cu was used for the oxide magnetic film 52 as a non-magnetic layer 4 at 3OFe₄ film and the metal magnetic film 32, as a nonmagnetic membrane 33 for switched connection, Ta was used as an object for protective coats, and Pt was used for Ru as an object for up electrodes. The configuration of the created film is shown below.

[0214] example sample 31 Cu (100) /Pt (10) /Ta (3) /Pt_{0.5}Mn_{0.5} (15) /Co_{0.9}Fe_{0.1} (3) -- /Ru(0.7)/Co_{0.9}Fe_{0.1}(2) / Fe₃O₄(0.6)/Co_{0.9}Fe -- 0.1(2) / Cu(2.2)/NiFeCo(2) / Fe₃O₄ (0.6) / NiFeCo(1) / Ru (0.7) / NiFeCo(2) / Ta (3)/-- Pt (10) -

After leaving a Cu/Pt lower electrode and carrying out patterning of the created magneto-resistive effect element to 0.3-micrometer angle, the whole is insulated by 2Oaluminum₃ film. Thus, the up electrode 21, The through hole with the lower electrode 11 was opened, the sense line 23 which consists of Cu was independently connected to the upper part and the lower electrodes 21 and 22, it insulated by 2Oaluminum₃ film further, the word line 22 which consists of Cu was formed, and it considered as the memory device 1700 of a configuration as shown in drawing 17. It turned out that flux reversal of the free layer 5D which passes current to a word line 22 and changes from NiFeCo/Ru/NiFeCo to it like an example 15 is carried out, information is written in, resistance change of the sink sense line 23 is measured for current to a word line 22 next, the actuation is checked, and a memory device 1700 can be constituted. Thus, it was checked that the memory device which it was checked that the memory device 1700 using the magnetic resistance element 9 of this invention operates also with the cell size of 0.3-micrometer angle, and was created in the examples 15 and 16 is nonvolatile.

[0215] (Example 17) Magneto-resistive effect element 1100B of the configuration of drawing 11 B was created by the spatter using the membrane formation equipment which has a pluralism spatter cathode. In this case, as a target, it considered as Pt_{0.5}Mn 0.5 and the substrate layer 7 as an object for the magnetization revolution control layers 2, and as Ta and a metal magnetic layer 32, as Fe 0.1 and an object for the Co_{0.9} nonmagnetic membranes 33, Fe₃O₄ was used as magnetic film 51 as a non-magnetic layer 4. As inert gas for sputtering, although there were Ar, Kr, Xe, etc., Ar gas was used in this case. Moreover, only when creating the oxide magnetic films 31 and 52, about 1% of O₂ gas was introduced

together with Ar gas. The object which adds this oxygen gas is for adjusting the amount of oxygen of the oxide magnetic film formed when sputtering was performed in the case where the amount of O of 3OFe4 target is comparatively low, or a high vacuum, since the spatter was carried out in the high vacuum for a long period of time. As an amount of oxygen to introduce, 10% or less degree of total gas pressure is suitable.

[0216] Since the spatter was carried out in the above-mentioned prolonged high vacuum, after the amount of O of 3OFe4 target exhausted the inside of a chamber to 1×10^{-9} or less Torr using 3OFe4 target which is comparatively low, sputtering gas was introduced until it was set to 0.8mTorr(s), and the magneto-resistive effect element of the next configuration was created on Si substrate.

[0217] example sample 32 Ta -- (-- three --) -- /-- Pt -- 0.5 -- Mn -- 0.5 -- (-- one --) -- /-- Co -- 0.9 -- Fe -- 0.1 -- (-- two --) -- /-- Ru (0.7) -- /-- Co -- 0.9 -- Fe -- 0.1 (1.5) -- /-- Fe -- three -- O -- four -- (-- one --) -- /-- Co -- 0.9 -- Fe -- 0.1 (1.5) -- /-- Cu -- (-- two --)

Moreover, the conventional example sample J which does not have the layer of an oxide magnetic film for a comparison was created.

[0218] the conventional example sample J Ta -- (-- three --) -- /-- Pt -- 0.5 -- Mn -- 0.5 -- (-- one --) -- /-- Co -- 0.9 -- Fe -- 0.1 -- (-- two --) -- /-- Ru (0.7) -- /-- Co -- 0.9 -- Fe -- 0.1 -- (-- three --) -- /-- Cu -- (-- two --) -- /-- Co -- 0.9 -- Fe -- 0.1 -- (-- one --) -- /-- nickel -- 0.8

Thus, the property of the created magneto-resistive effect element was compared by the same method as an example 12. The result is shown in a table 14.

[0219]

[A table 14]

試料	MR比 (%)	Hp (kA/m)
実施例サンプル 32	13.1	80
従来例サンプル J	7.5	80

[0220] As the result of a table 14 shows, it turns out that the example sample 32 of this invention shows big MR ratio although the magnitude of Hp is not different from the conventional example by the effect of the oxide magnetic films 31 and 52.

[0221] Moreover, the example sample 33 which used 12OA3 target instead of the oxide magnetic film 52, and formed 12OA3 film which is an oxide nonmagnetic membrane with the example sample 32 was also created.

example sample 33 Ta -- (-- three --) -- /-- Pt -- 0.5 -- Mn -- 0.5 -- (-- one --) -- /-- Co -- 0.9 -- Fe -- 0.1 -- (-- two --) -- /-- Ru (0.7) -- /-- Co -- 0.9 -- Fe -- 0.1 (1.5) -- /-- Fe -- three -- O -- four -- (-- one --) -- /-- Co -- 0.9 -- Fe -- 0.1 (1.5) -- /-- Cu -- (-- two --)

In this case, although MR ratio was equivalent to 12.8% and the example sample 32, the soft magnetic characteristics of free layer 5A deteriorated, and it increased to 10Oe(s) with the example sample 33 to the reversal magnetic fields (coercive force) of free layer 5A of the example sample 32 being about 3 Oe(s). As for this, for a certain reason, not only the electronic specular reflection effect but the effect of improving elasticity magnetic properties is considered by the oxide magnetic film 52.

[0222]

[Effect of the Invention] The magneto-resistive effect element of this invention realizes big MR ratio compared with the conventional thing, by using this, makes possible the magneto-resistive effect mold arm head of high power, and carries out possible [of the magnetic recording medium of super-high density] using this arm head further. Moreover, if the magneto-resistive effect element of this invention is used, it is nonvolatile and the magneto-resistive effect memory device of high density can be created.

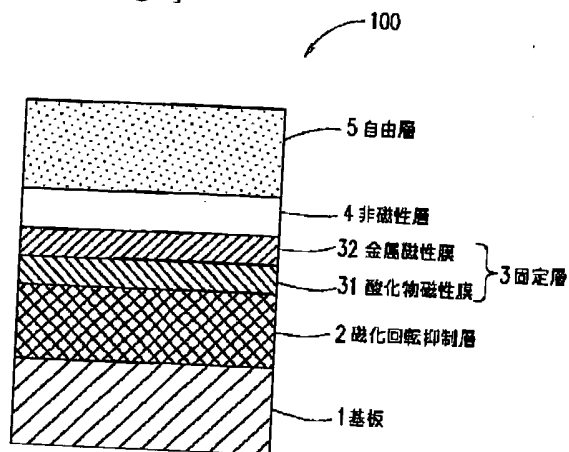
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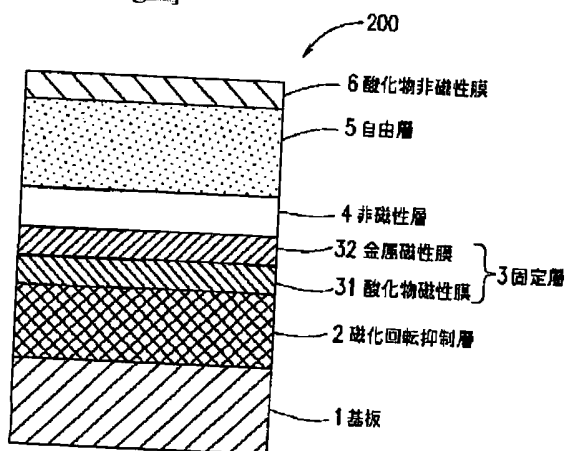
1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. **** shows the word which can not be translated.
3. In the drawings, any words are not translated.

DRAWINGS

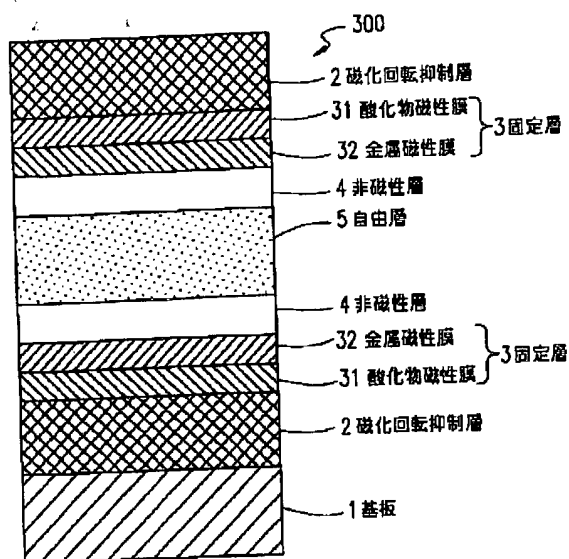
[Drawing 1]



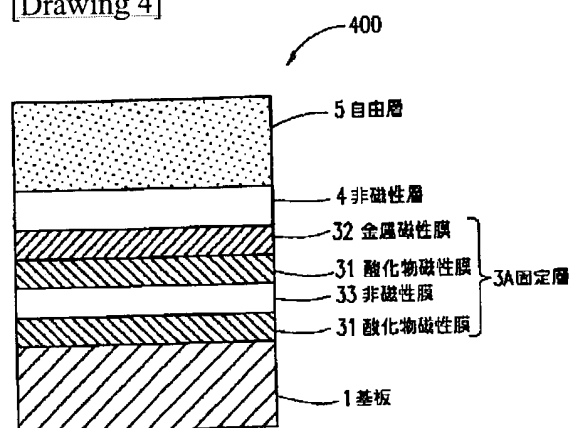
[Drawing 2]



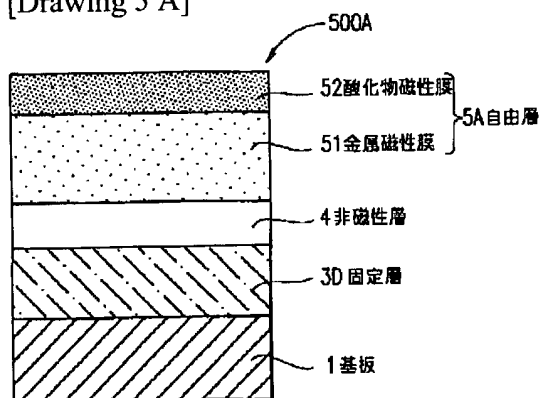
[Drawing 3]



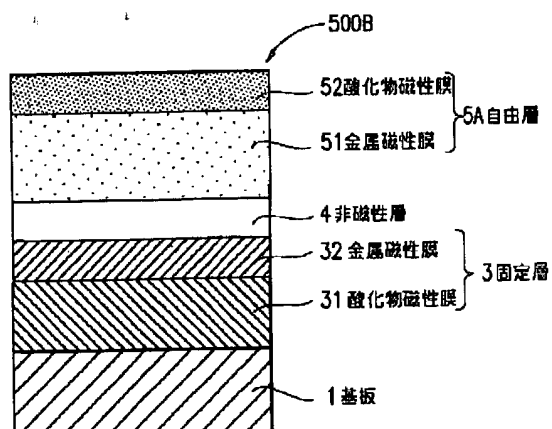
[Drawing 4]



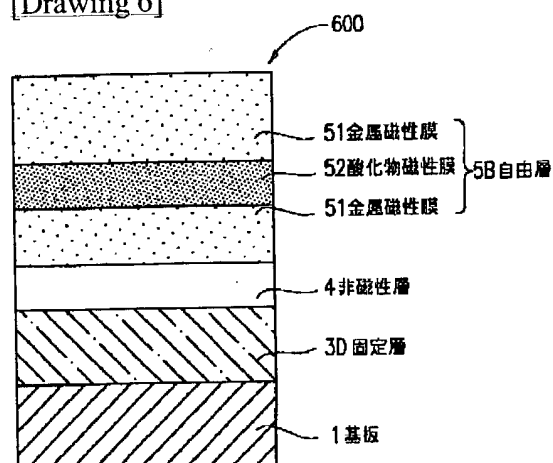
[Drawing 5 A]



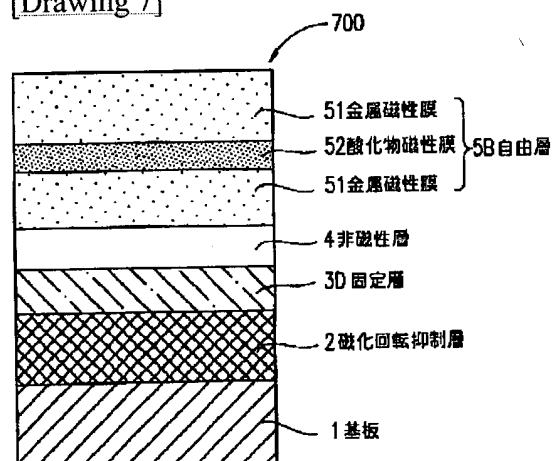
[Drawing 5 B]



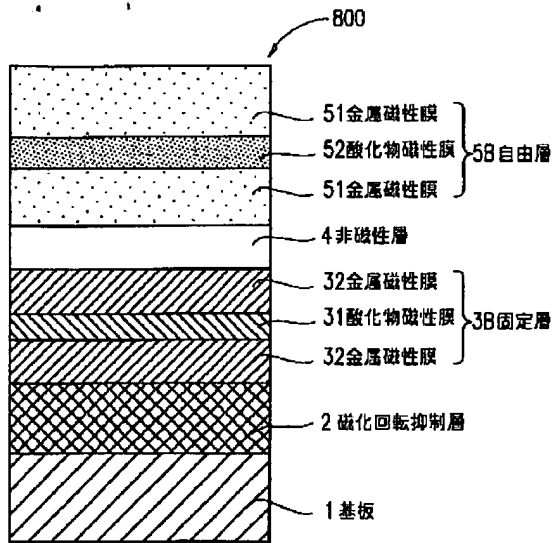
[Drawing 6]



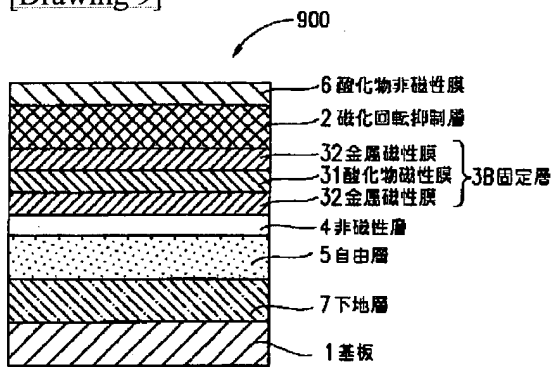
[Drawing 7]



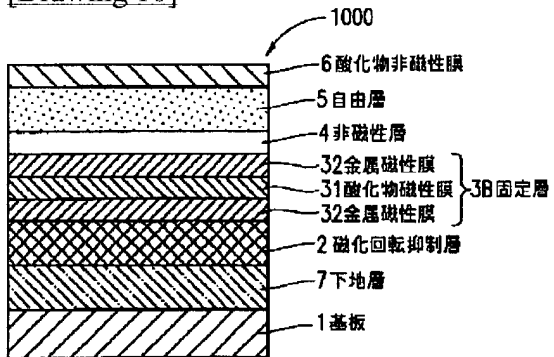
[Drawing 8]



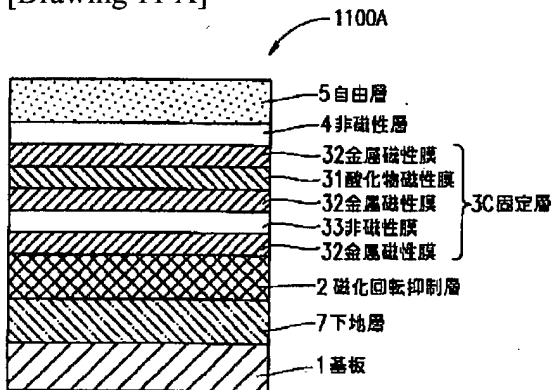
[Drawing 9]



[Drawing 10]

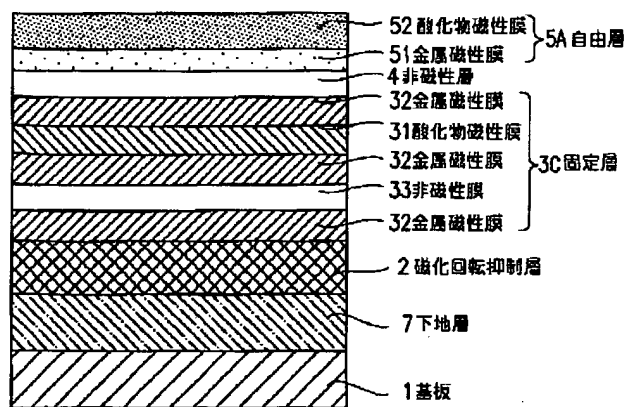


[Drawing 11 A]



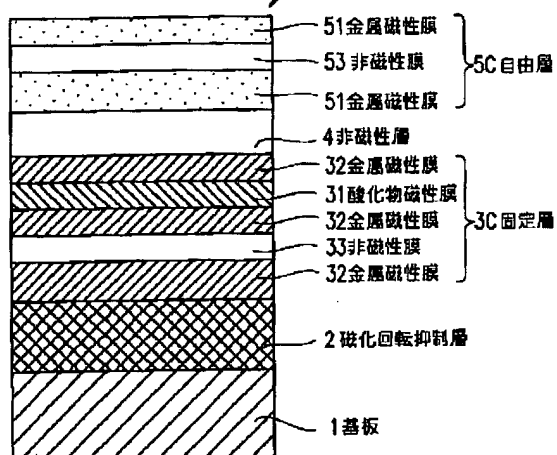
[Drawing 11 B]

1100B



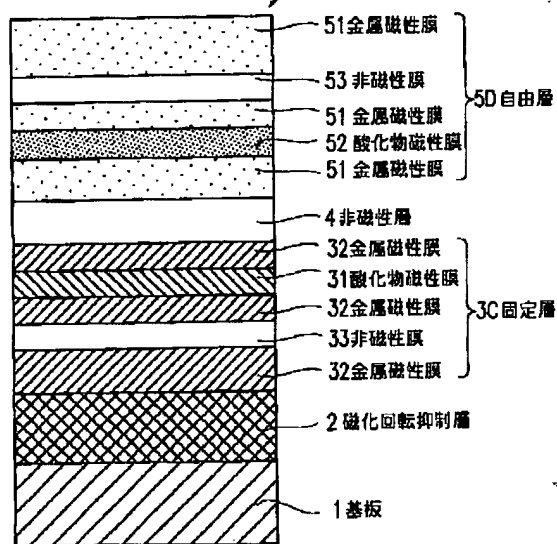
[Drawing 12]

1200

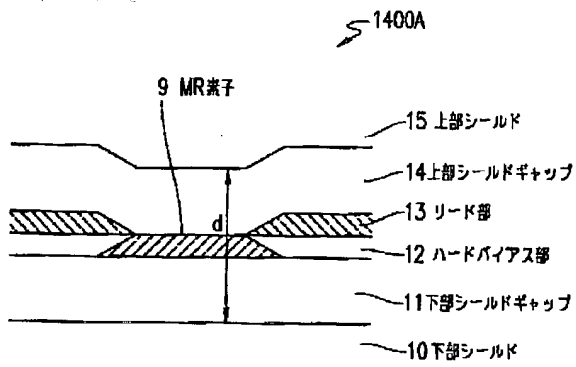


[Drawing 13]

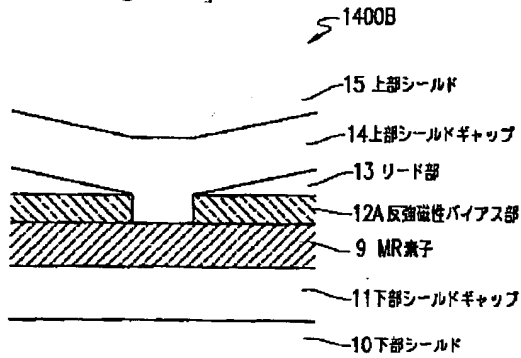
1300



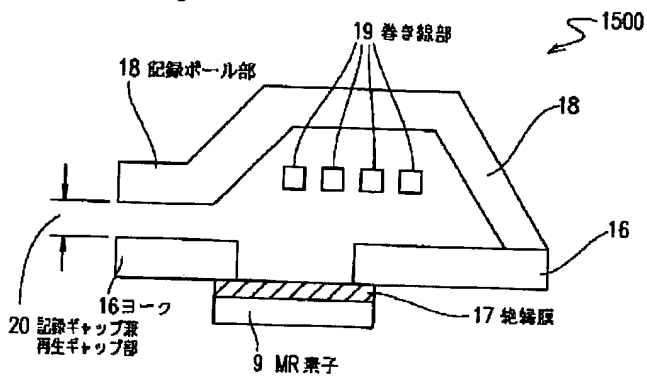
[Drawing 14 A]



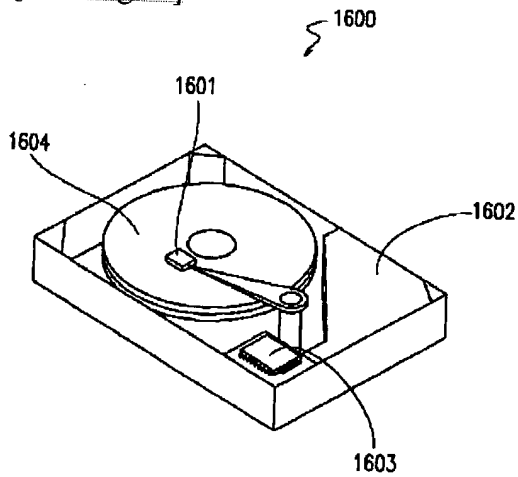
[Drawing 14 B]



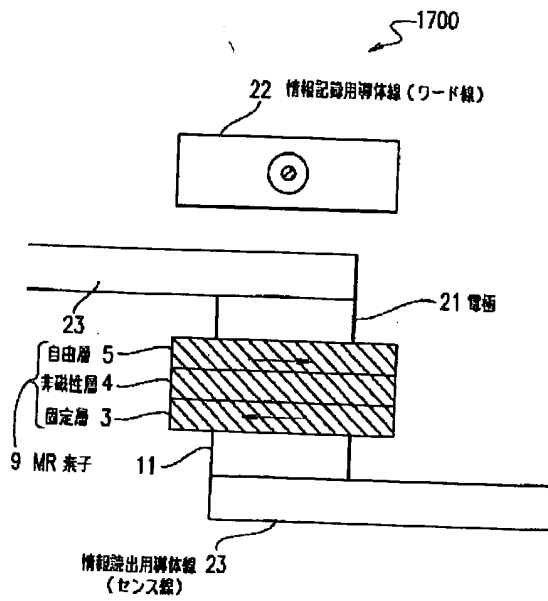
[Drawing 15]



[Drawing 16]



[Drawing 17]



[Translation done.]